# SECTION 6.0
# CHANNEL ASSESSMENT

## 6.1 INTRODUCTION/STATEMENT OF THE PROBLEM

The principal objective of this analysis is to define the location of major process regimes that govern channel morphology and channel changes. This includes describing general types and strengths of linkages between terrestrial and aquatic systems. Such an analysis is based on general theoretical considerations of mountain drainage basins and information on historical conditions. As a consequence, an emphasis is placed on identifying major process regimes and the juxtapositions of different regimes, and less emphasis is placed on collecting detailed information on present, site-specific morphological conditions. Refer to the Fish Habitat Assessment for inventories of present channel and habitat characteristics.

The Level 2 channel assessment in the Acme WAU is also designed to address several fish habitat concerns, including: 1) the effects of debris flow sedimentation and dam-break floods on fish habitat in lower portions of the steep mountain tributaries located on or near the floodplain of the South Fork Nooksack River; 2) the effects of decreasing riparian forests and large woody debris on channel morphology and fish habitat in the lower portions of the mountain tributaries and in the South Fork Nooksack River; 3) the effects of agriculture and flood control structures on the morphology of the active channel and floodplain of the South Fork Nooksack River; and 4) the relative proportion of erosion originating from the Acme WAU compared to the remainder of the South Fork watershed. Table 6-1 contains a cross referencing between analysis results contained in this chapter and the list of "products" recommended in the module. Refer to Appendix 6-1 for a review of discretionary procedures allowed when conducting a channel assessment.

## 6.2 BASIN OVERVIEW

The Acme WAU (drainage area approximately 90 $km^2$, 36 $mi^2$) encompasses approximately the lower 20% of the entire South Fork Nooksack watershed (total area = 460 $km^2$, 186 $mi^2$). The lowest gradient portion of the South Fork Nooksack River ($< 0.002$) flows through the Acme WAU (Figure 6-1), and as a result, the largest floodplains (and terraces) in the South Fork Nooksack watershed are located there. The low gradient of the South Fork Nooksack in the Acme WAU historically resulted in the formation of large gravel bars and log jams (see Section 6.5.1). The low gradient South Fork Nooksack floodplain and terrace is the largest single landform in the Acme WAU and comprises approximately 40% of the entire area.

The Chuckanut sandstone formation underlies the steepest areas including the basins of Sygitowicz, Falls and Standard Creeks in the northwest, and the Van Zandt Dike area in the northeast, and as a result shallow landsliding and debris flows are concentrated in those areas (see Mass Wasting Assessment). Phyllite bedrock underlies the southern portion of the WAU, and includes portions of McCarty and Jones Creek basins in the southwest, and south of Tinling Creek. Because of the weaker and more highly weathered Phyllite, the southern portions of the basin are

Table 6-1 This is a guide for cross referencing the customized channel assessment of the Acme WAU with the recommended products (and forms) listed in the Channel Assessment module (Table E-1).

1) Channel segment map (Map E-1): Section 6.3 Figure 6-2; Table 6-2.

2) Channel segment worksheet (Label form E-1): Section 6.4; Mass Wasting Assessment; Figures 6-1, 6-3, 6-4; Appendix 2.

3) Channel Disturbance worksheet (Label form E-2): Section 6.4 and 6.5; Figures 6-3 through 6-8.

4) Narrative summarizing historic watershed riparian width pattern: Section 6.4 and 6.5; Figures 6-3 through 6-8.

5) Site selection rationale (Form E-3):
   A) Used most of the data collected for the Fish Habitat Module which covered the majority of all fish-bearing channels.
   B) For specific geomorphic analyses, justification is implicit with the type of geomorphic process that was investigated, for example:
      i) mass wasting effects on channels - Sygitowicz, McCarty, Falls, Jones Creeks;
      ii) coarse sediment supply: Sygitowicz, McCarty, Falls, Jones, Tinling Creeks and small tributaries draining the Devil's Slide;
      iii) fine sediment supply: all segment types were sampled, refer to Appendix 3;
      iv) pool-forming factors: (See Fisheries Assessment); Section 6.6.2;
      vi) role of peak flows: Jones and Sygitowicz Creeks (see Hydrology Module);
      vii) morphological changes to the South Fork Nooksack and its floodplain: South Fork Nooksack River

6) Field Forms (Label form E-4): Most of the suggested data in addition to other data presented and discussed in Sections 6.6 through 6.7, and data presented in Figures 6-1 through 6-9 and in Appendices 2 and 3.

7) Segment diagnostic worksheet (Label form E-5): Data presented in all sections in the channel module and all figures.

8) Geomorphic unit map: not needed as a separate map; information is contained in landslide inventory and mass wasting map unit maps, and channel segment map (Figure 6-2).

9) Geomorphic unit worksheet (Label form E-6): Table 6-2.

10) Narrative describing dominant geomorphic processes and condition: throughout channel assessment report;

11) Narrative describing habitat-forming processes by cluster: throughout channel assessment report, specifically in section 6.5 and 6.7.

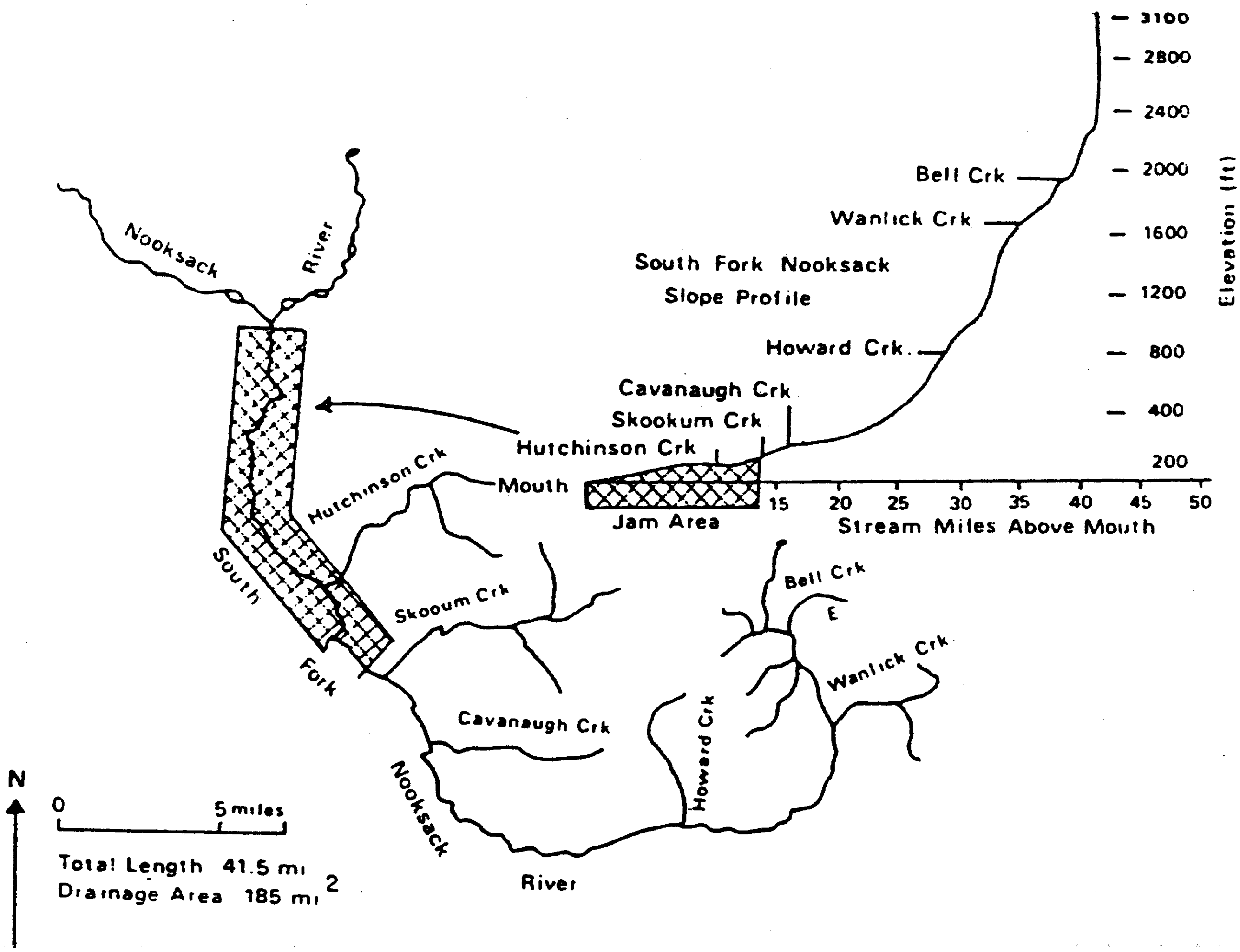


Figure 6-1 Plan map and longitudinal profile of the entire South Fork of the Nooksack River showing the approximate location of large historical debris jams (from Sedell and Luchessa, 1982).

much less steep and contain little shallow landsliding and debris flows. However, the phyllite bedrock allows formation of deep-seated landsliding in the Jones Creek basin, and to a smaller, localized areas of deep-seated mass wasting in the southern portion of the WAU (see Mass Wasting Assessment).

Although episodic mass wasting, and other more continuous erosion processes in the bus-basins of the Acme WAU, deliver sediment to the South Fork Nooksack River, the majority of sediment supply to the Nooksack River in the Acme WAU originates from sources outside and upstream of the WAU. The proportion of sediment originating from within the Acme WAU to the South Fork Nooksack River can only be approximated in this watershed analysis because a basin-wide sediment budget does not exist. First, based on drainage area alone and assuming that erosion sources are equally distributed within the basin, the proportion of sediment generated from within the Acme WAU (the long-term average) and delivered to the South Fork Nooksack River should be approximately equivalent to 20% of the total basin area. Because approximately 40% of the Acme WAU consists of terraces and floodplains, only the remaining 60% of the area produces sediment that can be delivered to the South Fork (i.e. floodplain and terrace reflect net sediment storage). Finally, most of the steep, erosion producing basins in the Acme WAU (e.g. Sygitowicz, Standard, McCarty, and Jones Creek, etc.) have created fans on the Nooksack floodplain where much of the sediment is stored (sediment delivery ratio estimated ~0.5 based on field observations). Hence, it is hypothesized that on average less than 10% of the basin sediment yield for the North Fork basin originates from the Acme WAU. However, it is also possible that during certain periods of time, the Acme WAU could contribute a higher proportion of sediment such as during fires, large storms, or land use activities.

## 6.3 CHANNEL GEOMORPHIC SEGMENTS

There is a diversity of channel types in the Acme WAU, ranging between steep, debris flow-prone first- and second-order channels, and the low-gradient and wide South Fork Nooksack River with its (potentially) extensive floodplains. Channel geomorphic segments are identified based on field measurements and observations of process and landform, geographic location and map-based criteria. Variations in channel gradients, and to a lesser extent, channel widths, valley confinement, drainage area, substrate sizes, source of water (i.e. upland basin versus floodplain groundwater), proximity to hillslopes (i.e. mass wasting influences) and existence of floodplains are used in the Acme WAU to classify channel segments.

Longitudinal profiles (measured from 1:24,000-scale topographic maps) of all of the major channels in the Acme WAU, including the South Fork Nooksack River, Jones, McCarty (north and south forks), Standard (north and south forks), Sygitowicz (north and south forks) and Tinling Creeks are used to support channel segmentation are they are located in Appendix 6-2. The longitudinal profiles, in addition to field identification of process (such as debris flow versus fluvial) and form (such as fan versus floodplain), were used to classify the channel network in the Acme WAU into three broad categories: 1) mountain tributaries including their fans (>4% gradient); 2) tributary channels on the Nooksack floodplain with upland or floodplain sources of water (<1% gradient); and 3) the South Fork of the Nooksack River, including its floodplain (<1% gradient).

High-gradient mountain tributaries typically have little gravel in storage with the exception of local storage reservoirs behind woody debris and boulder steps, and hence they are often sediment supply limited except during periods of heightened erosion in the basin. High-gradient channels prone to debris flows and dam-break floods are often armored by cobbles and boulders, and channel bedrock may be discontinuously exposed. Typically, mountain tributaries are constrained by hillslopes (inner gorges or canyons) and boulder-filled terraces, although terrace development is limited. The fans at the mouths of all mountain tributaries are comprised of debris flow deposits primarily in their proximal (upstream) portions and alluvial sediments in their distal (downstream) portions. The lowest portions of many of the mountain channels traverse the low-gradient Nooksack floodplain and therefore would contain larger amounts of gravel and more woody debris under natural conditions.

The mountain tributary channels oriented approximately subparallel to the South Fork Nooksack River are of two types. The first type receives upland sources of water. The second type is formed by mainstem bifurcations (anastomising channels during flooding and sedimentation episodes), and flows originate from the Nooksack River or from groundwater within the floodplain; both of these types are referred to as floodplain slough channels.

The descriptions of the eight channel units are located in Table 6-2 and the units are delineated on a 1:24,000-scale topographic map in Figure 6-2 by color codes.

## 6.4 HISTORIC TRENDS

Historic trends can refer to the history of erosion, streamside vegetation, channel and floodplain morphology and fish habitat during recent times, typically the period covered by aerial photography and early mapping. In the Acme WAU, aerial photography extends back to 1940 and mapping of the South Fork Nooksack River and its floodplain extends back to 1885. There is little historical information available regarding reach-scale channel morphology and fish habitat in the WAU.

### 6.4.1 Forest Cover including Riparian Zones

For a complete description of changing upland and floodplain forests and vegetation see the Riparian Assessment. The following is a brief summary of the history of forest cover that has relevance to the Channel Assessment. A large portion of the upland forests on the west side of the WAU were apparently burned by wildfire in the mid 1800s. Historically, the extensive floodplain of the South Fork Nooksack River contained a vegetation community comprised of conifer trees, including cedar and

Table 6-2 Descriptions of the stream and river channel segments in the Acme WAU.

SEGMENT #1. South Fork Nooksack River. Low gradient (<0.001), gravel bed meandering river. Gravel and cobble are the dominant substrates. Alternating pool and riffle morphology controlled by the distribution of meanders. Woody debris locally important in forming pools. Extensive gravel bars (point and mid channel bars), although bars have been lessening in number and size over time because of widespread diking and removal of woody debris. Segment #1 includes the natural meander belt. Generally unconfined, but large portions of river artificially constrained by dikes. The South Fork has been extensively modified and its morphology in 1994 is very different to what it was in the 1800s and early 1900s (see Section 6.5).

SEGMENT #2. Historic meander belt of the South Fork Nooksack River based on the distribution of slough channels mapped in 1938 and gravel bars in the 1943 aerial photographs. Meander belt could include extensive riparian forests, slough channels, mainstem secondary channels and wetlands.

SEGMENT #3. Slough channels formed by mainstem bifurcations. Gradient similar to mainstem South Fork Nooksack River (<0.001). Substrate similar to mainstem (gravel and cobbles), although sand may dominate due to overbank flooding. Channels fed by groundwater are expressions of the hyphoreic zone and other slough channels may be fed directly from the mainstem Nooksack. Pool morphology and low flow velocity are characteristic because of low discharge and low gradient. Woody debris important components of pool habitat and it provides cover. Unconstrained.

SEGMENT #4. Floodplain tributaries with upland sources of flow. Gradient similar to mainstem South Fork Nooksack River (<0.001). Substrate dominated by gravel, some sand and cobble. Woody debris important pool forming agent. These tributaries often flow sub parallel (downstream) to the mainstem South Fork. Pool morphology and low flow velocity are characteristic because of low gradient and low discharge in the summer. Flow may go subsurface below the mouths of the mountain tributaries. Unconstrained.

SEGMENT #5. Alluvial and/or debris flow fan. Debris flow deposits occur in the proximal portions of the fan and alluvial deposits in the distal portions (i.e. downstream). Gradient between 0.08 and 0.04. Substrate depends on sediment supply and abundance of obstructions. High sediment supply yields gravel substrate while low supply leads to boulder and cobble substrate. Wood important in formation of pools. Debris flows or finer-grained mudflows may enter lower, alluvial fan area. Generally unconstrained in distal portions, constrained in proximal portions. (See Appendix 6-5)

SEGMENT #6. Tributaries with upland drainages and generally below Segment #5 (alluvial and debris flow fans). Tributaries oriented perpendicular to floodplain of mainstem Nooksack River and therefore gradients range between 0.04 and 0.001. Gravel substrate dominates, but supply of sediment in tributary will control substrate to some extent. Wood is an important pool-forming agent. Generally unconstrained.

SEGMENT #7. Mountain tributary channels. Gradient > 0.10. Substrate dominated by boulders and cobbles, although high sediment supply and local obstructions will lead to a finer-textured bed. Typically cascade and step-pool morphology. Wood is important in sediment storage and pool formation. Generally constrained between inner gorges and canyons, and by hillslope deposits including landslides, debris flows, treefall and rockfall. Dam-break floods are likely in this segment. Debris flows may be able to travel through portions of these channels.

SEGMENT #8. Upland channels directly below small lakes. Gradient 0.02 to 0.06; cobble, boulder and gravel substrate (generally low sediment supply). Wood is an important pool-forming agent. Varies between constrained to unconstrained.

spruce and extensive areas of hardwoods, including alder, black cottonwood, and big leaf maple. The 1885 surveyors referred to the bottom lands of the floodplain as a "vine maple jungle", which also includes species such as devils club and salmonberry.

Harvest of timber in the upland forest began in the 1940s and continues to present. The majority of the conifer forests in the uplands has regrown and is comprised of second-growth timber ranging from immature to 60 year old trees. Permanent clearing of the vast majority of South Fork floodplain vegetation, including riparian forests, for agricultural purposes began in the late 1800s and was virtually completed by the mid 1900s.

### 6.4.2 Erosion by Mass Wasting

Mass wasting was detected using aerial photography in most of the steep subbasins contained in the Acme WAU (refer to the Mass Wasting Assessment). Approximately 175 landslides and debris flows were inventoried in the Acme WAU between 1970 and 1994 using aerial photography and field observations. The majority of these (approximately 80%) were associated with forestry activities such as timber harvest and road construction. Debris flows and dam-break floods have occurred in the mountain stream portions of most of the major upland drainages (Sygitowicz, Standard, McCarty, Falls, and Jones Creeks ) during the last 30 years. In addition, debris flows and dam-break floods have deposited sediment and debris on most of the major alluvial/debris flow fans and on the terrace/floodplain of the Nooksack River.

Landsliding in the Acme WAU has been an important process during the Holocene (last 10,000 years). Evidence for this includes numerous bedrock hollows (i.e. landforms created by persistent sliding), and debris-flow and alluvial fans at the mouths of most tributaries (some fans, such as Standard Creek have been truncated by bank erosion of the Nooksack River). The historical rate of landsliding or erosion has not been steady, but was probably concentrated during large rainstorms and following wildfires (Orme, 1990). Information on the natural erosion regime (regime includes frequency, magnitude, spatial distribution and composition) would be useful for understanding the effects of land-use related erosion on stream ecosystems at the watershed scale over longer time periods ($10^2$ - $10^3$ yrs). No information is available on the erosion regime prior to forestry activities in the subbasins of the Acme WAU. Some of the effects of forestry-triggered erosion on channel morphology and fish habitat are investigated later in this chapter.

### 6.4.3 In Stream Woody Debris

There is historical evidence that the South Fork Nooksack River in the Acme WAU contained extensive river-spanning log jams (Harman et al., 1986). During the twentieth century, log jams were pulled, burned and blown up, which removed virtually 100% of the large wood from within the channel and floodplain of this portion of the South Fork Nooksack.

There is no information on historical (pre-Euro land use) levels of woody debris in the mountain streams (Segments 3 - 7). Because of timber harvest in the upland basins and clearing on the Nooksack floodplain for agricultural purposes, the amounts of woody debris in these channel segments should be lower than what they were during pre-Euro times. Information on the present amounts of woody debris in the tributaries and in the mainstem Nooksack River is contained in the Fisheries Assessment.

### 6.4.4 Channel and Floodplain Widening

Channels and floodplains can widen in response to flooding and to an increase in sediment storage (Benda et al., in press). An increase in sediment storage within a reach arises usually because of an increase in erosion upstream. Channel widening can also occur when riparian forests are cut leading to a reduction in effective bank cohesion because of loss of root strength (Collins et al., 1995). Channel widening can be accompanied by a change in channel morphology (and therefore fish habitat) in the affected reach. For example, bed substrate may fine (from cobbles to gravels, or gravels to sand), pools may be reduced in area and depth, and channel braiding and the creation of secondary channels may increase. Smaller channels may also widen following debris flows and dam-break floods. Changes in channel and floodplain dimensions observed from historical aerial photographs can be used to infer changes in channel morphology and fish habitat.

Channel widening occurred along the lower reaches of many of the mountain tributaries following a major storm in the early 1980s. Debris flows and dam-break floods deposited sediment and woody debris on the alluvial fan and lower channels of Sygitowicz, Standard, Falls, McCarty and Jones Creek. Channels appeared to have widened during this event also because of channel aggradation that resulted in streams migrating across their fans and valley floors.

Historically (prior to the construction of flood control dikes), the South Fork Nooksack River and its active floodplain (unvegetated gravel bars) probably expanded in response to increasing sediment transport during large floods following heightened erosion in the watershed, and contracted during periods of lower erosion or during times of few floods which allowed vegetation to become established on gravel bars. In the South Fork Nooksack River in the Acme WAU, there has been a steady decline in the width of the channel and active floodplain since approximately 1938 (which probably began earlier) because of diking and log jam removal (see Section 6.5.2).

### 6.4.5 Nooksack River, and its Floodplain and Floodplain Channels

Of all the landforms in the Acme WAU, the South Fork Nooksack River and its floodplain and floodplain channels have been most affected (changed) by land use during the last century. Changes to the morphology, function, and habitat of the Nooksack River and its floodplain comprise a major fish habitat impact because the mainstem Nooksack and its slough channels were the most important aspect of fish in the Acme WAU and a major component of the aquatic ecosystem for the entire South Fork Nooksack Watershed. Therefore, a separate section in the Channel Assessment Chapter is allocated for a discussion of the modification of the Nooksack River and its floodplain.

## 6.5 MODIFICATIONS OF THE SOUTH FORK NOOKSACK AND ITS FLOODPLAIN AND FLOODPLAIN CHANNELS

### 6.5.1 The Natural River: Form, Process, Fish Habitat (pre 1940s)

The portion of the South Fork Nooksack River that is located in the Acme WAU contains the lowest gradient of the entire South Fork Nooksack River system (Figure 6-1), and is therefore a natural depositional area for sediment and wood originating upstream. As a consequence, the floodplain and terrace landform averages 5 km (2 miles) in width and comprises approximately 40% of the land area of the Acme WAU.

The following discussion reflects the processes, forms and habitats of the South Fork Nooksack River that existed prior to extensive river modifications. The low gradient (< 0.002) and unconfined character of the South Fork Nooksack River in the Acme WAU resulted in the deposition of numerous gravel bars which caused the river to have a braided and highly sinuous morphology (the river is no longer braided, see below). The multiple channels, large mid-channel gravel bars and islands are apparent in river maps created in 1885 and 1938. Figure 6-3 shows a comparison of the river plan form in years 1885, 1938, and 1991. Although the 1885 river map is not drawn in great detail, the highly sinuous nature of the river is apparent between the community of Van Zandt and the confluence with the North Fork Nooksack River. The 1938 river map shown in Figure 6-4, prepared by the State of Washington Department of Conservation and Development, contains much more detail and includes location of gravel bars and small sloughs on the Nooksack floodplain. Figures 6-3 and 6-4 also contain the shape and location of major gravel bars of the Nooksack River in 1991, and the differences among the river planforms in 1885, 1938 and 1991 are discussed below.

The low gradient and highly sinuous morphology of the South Fork River in the Acme WAU led to the development of extensive, river-spanning log jams. Harmon and others (1982) report that an extensive log jam or a series of log jams existed in the South Fork of the river between Skookum Creek and the confluence with the North Fork (30 km in length, 12 miles); Figure 6-1 shows the approximate location of the log jams. All of the major log jams have been removed from the lower South Fork Nooksack in the Acme WAU beginning in the late 1800s (and continuing to today) for the purposes of navigation and flood control.

The historical meandering of the South Fork Nooksack River in the Acme WAU, in conjunction with many log jams and the deposition of sediment, created numerous channels, many of which were abandoned by the river for periods of time. These

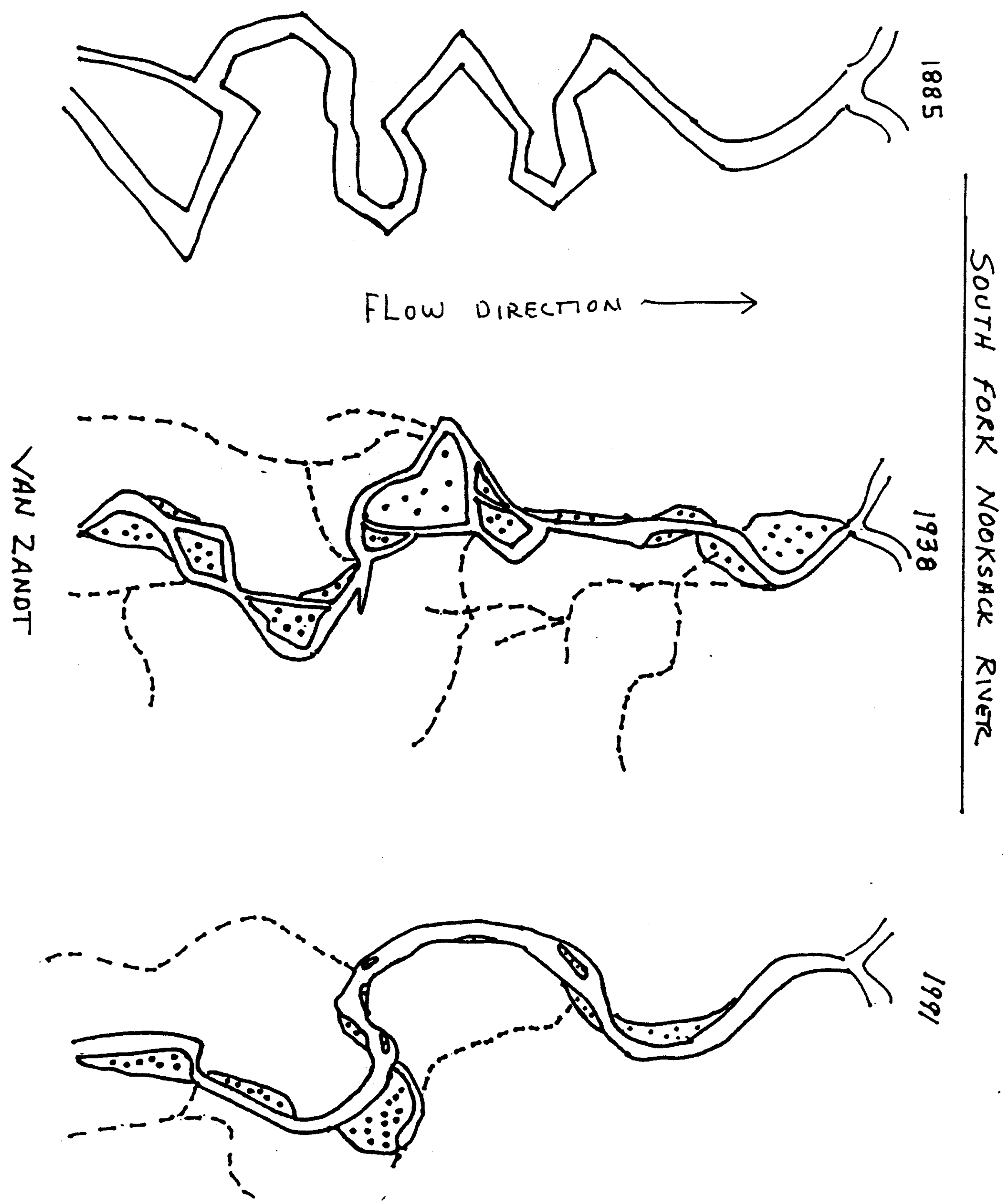


Figure 6-3 Sketches of the planform of the South Fork Nooksack River between Van Zandt and the confluence with the Middle Fork for 1885, 1938, and 1991. Sources include: (1885) the original government land survey (Iverson, 1885); (1938) State of Washington Department of Conservation and Development; (1991) 1991 1:12,000-scale aerial photographs and 1994 1:24000-scale U. S. Geological Survey topographic maps.

abandoned river channels contained flow either from the South Fork, the mountain tributaries, or they were fed by floodplain groundwater. These slough channels (because of their low flow velocities) were mapped in detail in 1938 (Figure 6-4) and comprised a major channel network in the Acme WAU during that time (most slough channels have been destroyed by 1991, see below).

The meandering South Fork Nooksack River and its extensive floodplains, slough channels, riparian forests, and log jams all contributed to the development of high quality and quantity of anadromous fish habitat (see Fisheries Assessment). In particular, the numerous slough channels and backwater areas of the lower Nooksack River would have supplied major rearing habitat for juvenile salmonids that would have been displaced by winter floods from the steeper mountain channels upstream throughout the South Fork watershed (drainage area 460 $km^2$, 186 $mi^2$). Hence, the lower South Fork Nooksack in the Acme WAU probably functioned as critical refuge habitat for the entire South Fork basin, particularly during large floods. Furthermore, the large gravel bars, their stability enhanced by large semi-permanent log jams, would have provided extensive spawning areas. Altogether, the Nooksack River and its slough channels would have provided excellent spawning and in particular rearing habitat. Hence, the river (and its floodplain) was historically the major fish habitat feature of the Acme WAU (in comparison mountain tributaries were only a minor component of the total fish habitat). Significantly, these floodplain habitat features have been all but eliminated by agricultural and flood control practices.

The natural floodplain of the Nooksack River (its approximate location is shown in Figure 6-2) flooded during major storms, and hence the floodplain stored floodwaters that likely reduced flood peaks downstream in the mainstem Nooksack River. In addition, the lower Nooksack River also stored sediment originating from upstream and therefore acted as a sediment capacitor that slowed the routing of sediment through the mainstem Nooksack River. These flood control aspects of the natural Nooksack River have been largely lost (see below).

### 6.5.2 Human Occupation of the Floodplain: Diking, Straightening and Loss of Slough Channels

Settlers began occupying the floodplain of the Nooksack River in the mid 1800s, and development continues today. The towns of Acme and Van Zandt, as well as numerous farms and private residences, are located in the natural floodplain of the lower South Fork Nooksack River. To combat flooding that occurred on the floodplain several strategies were employed that with varying success have protected the residences and other engineered structures on the floodplain. However, such river regulation strategies ultimately destroyed much of the form, function and habitat of the South Fork Nooksack River, which includes critical fish habitat and flood control (for downstream reaches). The flood control strategies included: 1) the removal or burning in place of log jams (Figure 6-1) to limit river braiding, meandering and the flooding of slough channels; 2) diking and associated straightening of the river to confine the South Fork Nooksack to a single channel and to limit floodwater access to the floodplain; and 3) the burial of floodplain slough channels to reduce floodwater access to the diked and protected floodplain, and to create more arable land for farming and grazing.

An aerial survey in 1994 revealed that approximately 60% of the length of the South Fork Nooksack River in the Acme WAU is diked; Figure 6-5 shows the approximate locations and extent of diking. The dikes are typically located at the outside of meander bends where the river has the highest potential bank erosion. The construction of dikes at these locations result in limiting the migration of the river, decreasing the size of gravel bars located on the opposite side of the river (i.e. point bars), limiting the opportunity to create secondary channels (i.e. braiding), limiting the formation of slough channels, and decreasing the opportunity for gravel storage. Furthermore, in 1994 there was not a single river spanning log jam in the lower Nooksack River, indicating essentially a 100% removal of large wood from the river since the late 1800s.

The effects of log jam removal, diking and burial of slough channels have created the river and floodplain morphology in 1991 evident in Figures 6-3 and 6-4. In Figure 6-3 the Nooksack River north of Van Zandt in 1991 has been straightened, multiple channels have been eliminated, and gravel storage has decreased. These changes are also evident at the scale of the entire South Fork in the Acme WAU in Figure 6-4. Figure 6-4 shows the dramatic loss in the number of slough channels since 1938 (reduction of 86%), and a large reduction in the length of the South Fork Nooksack (decreased by 37%), although the length of the primary channel has remained relatively constant, indicating that the loss of river length is due to elimination of secondary channels (e.g., see Figure 6-3, 1938 versus 1991). The length of riparian forests along the South Fork have decreased by 35% since 1940 (based on aerial photography). The comparisons between the river morphology of 1938 and 1991 are summarized in Figure 6-6. The total area of the channels and gravel bars along the entire length of the South Fork in the Acme WAU has decreased by approximately 40% . However, comparisons of channel area and gravel bar area between 1938 and 1991 indicate that the primary loss in area is because of the reduction of gravel bars (Figures 6-7 and 6-8). Most of the sediment contained in the gravel bars in 1938 has probably remained, becoming vegetated behind dikes or otherwise removed from extensive fluvial erosion. The straightening of the river has also led to a reduction in sharp meander bends (and their associated deep pools) in the river (50% reduction in river meanders of greater than $60^{0}$).

### 6.5.3 Landuse Effects: Loss of Sediment, Flood Control, and Quality Fish Habitat

The large gravel bars that formed historically in the lower South Fork Nooksack River (i.e. Figures 6-3 and 6-4) in the Acme WAU expanded when pulses of gravel entered the river which resulted in attenuating or diffusing large pulses of sediment through that segment of river (i.e. temporary storage of sediment in floodplains). Floodwaters

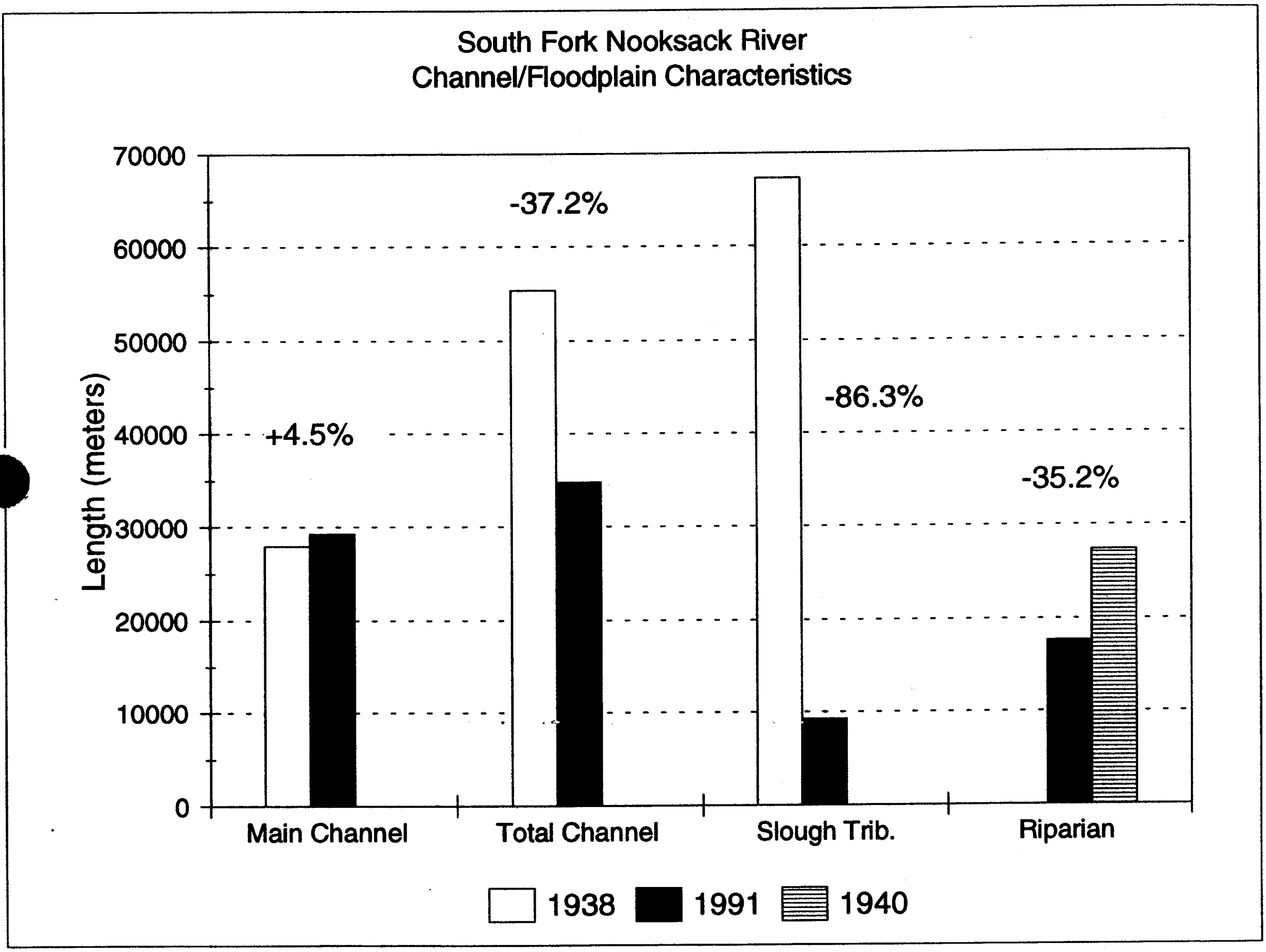


Figure 6-6 Changes in the lengths of the main channel, total channel (includes distributaries or secondary channels), slough tributaries, and riparian forests.

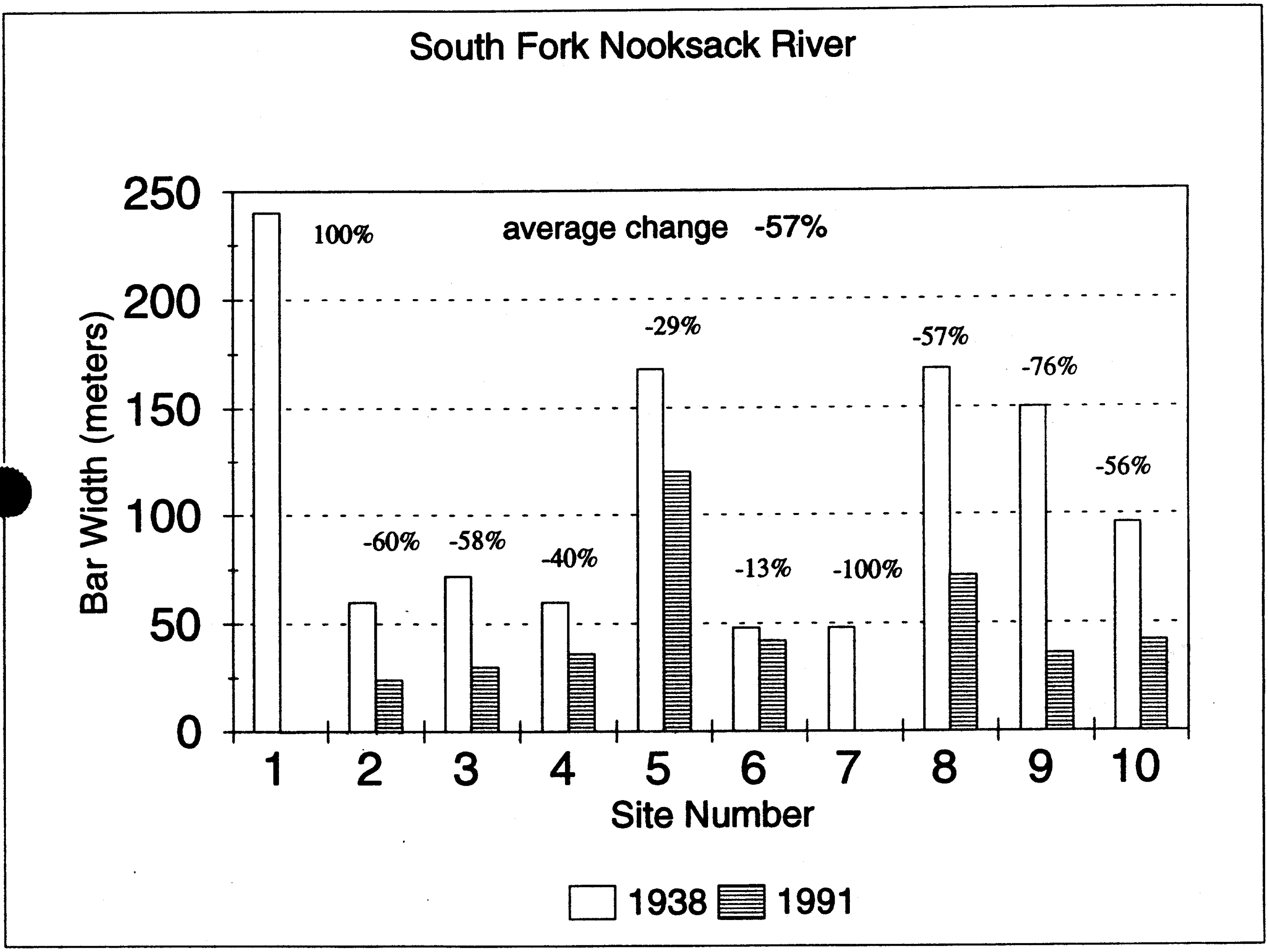


Figure 6-7 Changes in the widths of bars in the South Fork Nooksack River in the Acme WAU between 1938 and 1991.

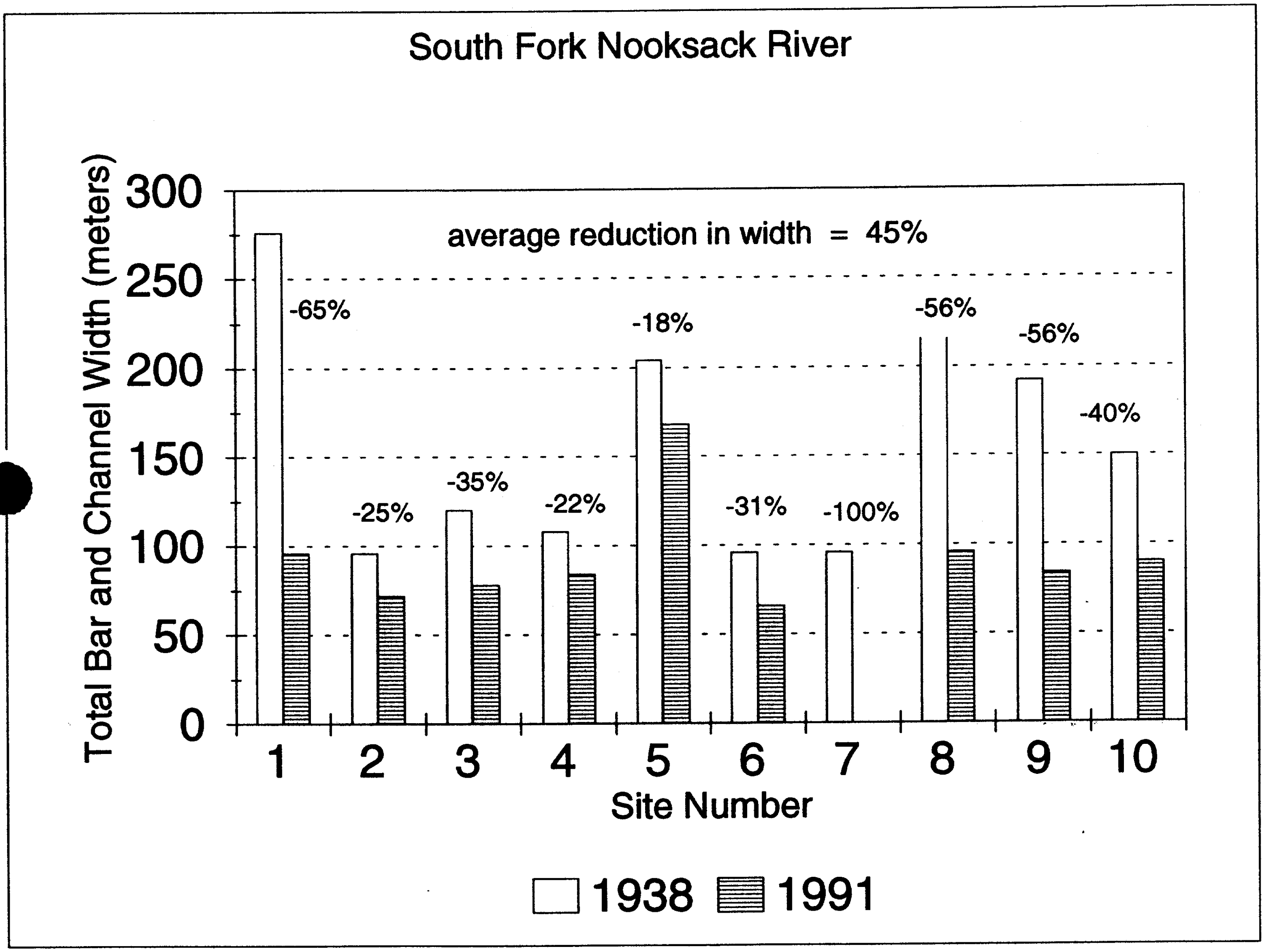


Figure 6-8 Changes in the widths of combined active channel and bars in the South Fork Nooksack River between 1938 and 1991.

spread over these gravel storage areas and also over the adjacent floodplain and into the slough channels. By reducing the ability of the river to store sediment in large bars in the lower South Fork, pulses of sediment entering the WAU from upstream do not have the opportunity to attenuate and sediment routing is more efficient in the regulated river. This may increase sedimentation (and therefore flooding) in the Nooksack River downstream of the Acme WAU.

Sedimentation of river channels during periods of high sediment transport can lower the flow capacity of a channel and result in higher over bank floods and this process creates and maintains floodplains. Undoubtedly this has occurred numerous times in the lower South Fork in the Acme WAU. Therefore, higher sedimentation downstream of the Acme WAU because of loss of floodplain storage of sediment (i.e. through diking) in the Acme WAU may increase downstream flooding in the Nooksack River.

The depositional environment of sediment and wood in the South Fork (contained in the Acme WAU) created what was probably some of the highest quality habitat in the entire South Fork Nooksack watershed. Abundant gravel bars created spawning habitat during the winter freshets. Large debris jams stabilized those bars and probably were responsible for numerous and deep pools. The laterally unstable river created multiple channels during floods that later became abandoned and evolved into slough channels (Figure 6-4, 1938). The slough channels, along with the more slack water secondary channels of the South Fork probably provided extensive winter rearing or refuge habitat for juvenile salmonids for the entire South Fork watershed. In addition, the highly sinuous South Fork probably would have had a lower gradient compared to the straightened river today. Lower gradients in combination with much higher roughness (i.e. extensive log jams) and slack-water channels should have resulted in higher sedimentation rates, including the deposition of fine sediment.

## 6.6 CURRENT STREAM AND RIVER CHANNEL CONDITIONS

### 6.6.1 Introduction

In the Acme Watershed Analysis the fish habitat assessment provided the majority of the channel information to determine present river and stream morphology. The history of major channel processes determined from aerial photography (Section 6.0, and Mass Wasting Assessment) is also used to understand current channel conditions. This section presents information on channels that is not covered in the Fish Habitat Assessment. The inventory of channel morphology contained here and included in the Fish Habitat Chapter covers primarily the mountain channel segments (Segments 5 - 7) and South Fork Nooksack River segment 1.

### 6.6.2 Pool-Forming Features

Pools in the Acme WAU are formed by wood, boulders, bedrock depressions, and banks (oftentimes in association with tree roots). Because the amounts of wood in the

South Fork Nooksack have been reduced for flood control purposes and in the mountain tributaries by debris flows, dam-break floods, logging of riparian zones and agriculture, the inventory of pool-forming features may not provide a completely accurate picture of natural pool-forming processes in the Acme WAU. Nevertheless, the pool-forming data presented in Figure 6-9 show some general patterns which are useful for understanding pool formation in various channel segments. Refer to Schuett-Hames et al. (1988) for a more complete inventory of channel features, including pool-forming elements in the South Fork Nooksack River.

The majority of pools in the mountain tributaries were created by logs and boulders. Although most of these streams have had recent debris flows and dam-break floods (see Mass Wasting Assessment) which have significantly reduced the amount of dispersed woody debris in streams and their associated pools, the dominance of log- and boulder-pools are likely a continuous feature of these streams (Figure 6-9). In mountain tributaries, wood-formed pools accounted for 46% of all pools. Therefore, although both the South Fork and the mountain tributaries have been impacted recently by land uses (river regulation and forestry practices, respectively) that would have changed the relative distribution of pool forming elements, the field inventories show the importance of wood as a pool-forming agent; under more natural conditions wood would have undoubtedly created a higher proportion of pools in both the South Fork Nooksack and also possibly in the mountain tributaries.

### 6.6.3 Channel Substrate Size and Fine Sediment

The sizes of channel substrates in the Acme WAU are controlled primarily by channel gradient and sediment supply, and secondarily by local obstructions, such as woody debris and boulders. The particle-size distribution of channel-bed material is important for fish habitat. In particular, the availability of gravels and the proportion of sands in gravels affect survival of salmonid eggs in redds. When the proportion of sands becomes greater than approximately 15% egg survival is limited (Fish Habitat Assessment).

Wolman pebble counts were conducted in Jones, Sygitowicz and McCarty Creeks to characterize the channel substrate in mountain tributaries. Histograms of the particle size distribution for the three streams (collected on the distal area of their fans) are contained in Appendix 6-3; particle size categories (i.e. pebble, gravel, cobble etc.) follow the Wentworth divisions. All of the channels show a dominance of coarser substrate indicative of mountain tributaries. However, Sygitowicz Creek contained much sand (35%) suggesting a chronic source of sand-size particles that may originate from old (1970s - 1980s) landslide and debris flow scars that were visible in the 1991 aerial photographs.

The proportion of fine sediment (< 0.8 mm) in the active channel compared to adjacent aggradational terraces (i.e. formed during high sediment supply) can be used to indicate current sediment supply in mountain tributaries. Two, 2-kg grab samples

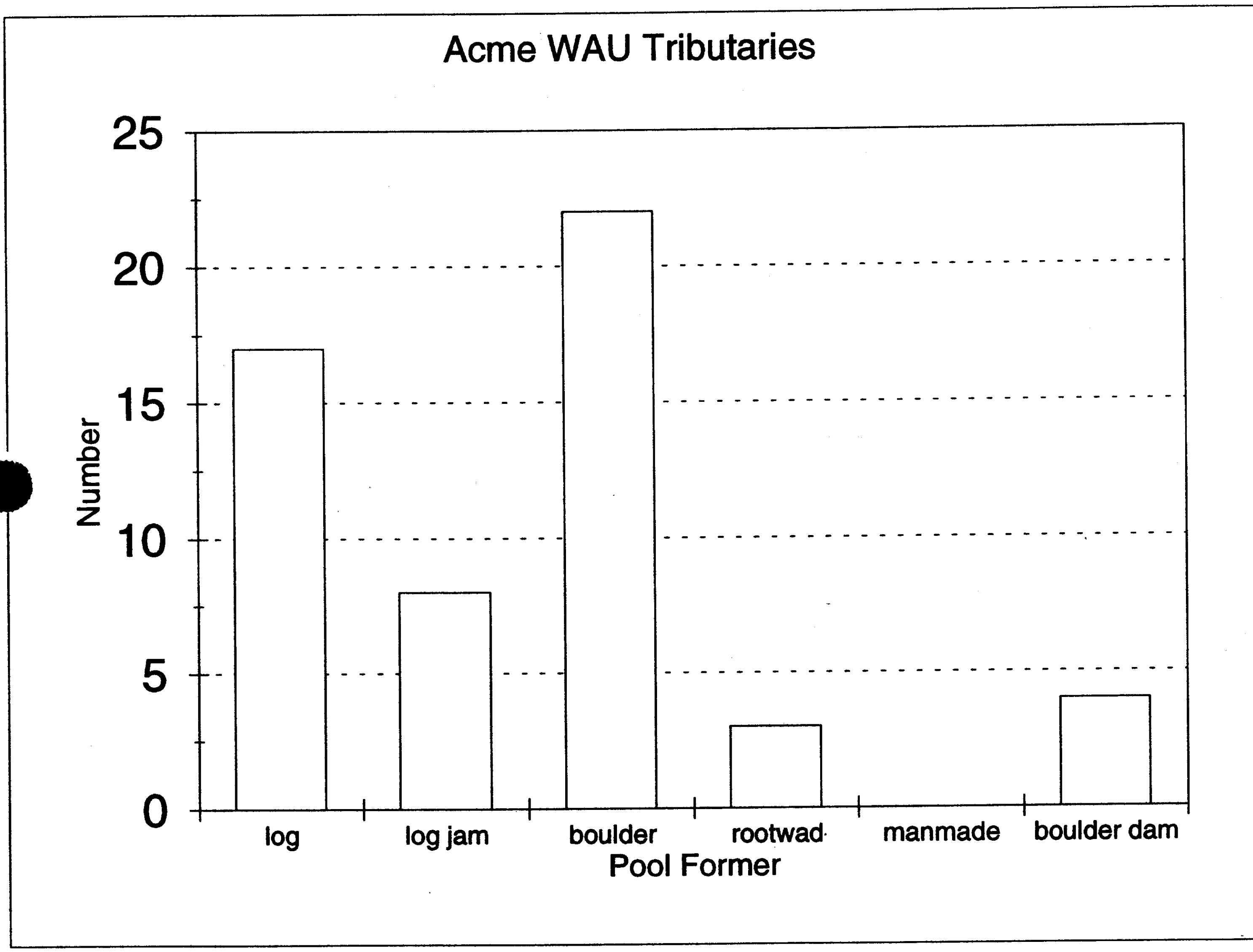


Figure 6-9 Distribution of pool forming elements in tributaries in the Acme WAU (using field data from the Fish Habitat Assessment).

were obtained in Sygitowicz, McCarty and Jones Creeks, and the average particle-size distributions are located in Appendix 6-3. Sygitowicz Creek contains approximately 20% fine sediment in the active channel (the terrace was incorrectly sampled and is not included). This particle size distribution suggests that Sygitowicz is continuing to incise into sediment deposits originating from mass wasting in the early 1980s, in combination with a continuous supply of fine sediment probably originating from landslide scars. McCarty Creek, sampled at two locations (Appendix 6-3), does not show significant differences in levels of fine sediment between active channel and terrace suggesting no large changes in sediment supply occurred during the last decade. The high levels of fines (20 - 30%) suggests a chronic source of erosion of sand size material. The landslide inventory indicates that inner gorge landsliding (mostly under canopy) may be the source of that sediment; the inner gorge area has been zoned as a High Mass Wasting Hazard (see Mass Wasting Assessment). The Jones Creek samples (Appendix 6-3) also show little difference between active channel and terrace suggesting also a chronic source of erosion in the basin. Field surveys during the Mass Wasting Analysis identified deep-seated landslides and extensive inner gorge landsliding as the source of aggradation of the Jones Creek fan (see also Jones Creek Alluvial Fan Study, Raines et al., 1996). All of the mass wasting and sedimentological evidence suggest that Jones Creek is aggraded near its fan, and that the stream is presently mining the stored sediment. The inner gorge area of Jones Creek has been zoned as a High Mass Wasting Hazard.

In-stream sediment samples collected during the Fisheries Assessment (Appendix 6-3) below the major portions of the fans in McCarty and Jones Creeks show lower levels of fine sediments (9% and 5% respectively). This suggests that fines are most elevated (and the channel most aggraded) in the main fan area, a condition which would be expected.

In-stream sediment samples were also collected during the fisheries assessment in Caron, VanZandt, Williams, Standard and Tinling Creeks (Appendix 6-3). Some of these tributaries drain more stable terrain (e.g., Caron and Tinling Creeks). Most of the segments showed low levels of fines (5 - 14%), with the exception of Williams Creek (30%). The high level of fine sediment in Williams Creek may originate from the very low gradient channels that were sampled on the Nooksack floodplain; many of the stream banks are comprised of sand (i.e. Nooksack floodplain sediments).

In-stream sediment samples were also collected in the South Fork Nooksack River during the fisheries assessment. Samples were obtained from six sites and the results are contained in Appendix 6-3. Levels of fine sediment (< 0.8 mm) ranged between 5% and 14% (average = 12%). These levels are similar to samples collected in the 1980s by the Lummi Tribe (Schuett-Hames, J. and D., 1984; 1987; 1988). The Schuett-Hames study was more detailed and comprehensive then the sampling that occurred in the Acme Watershed Analysis.

Summaries of the in-stream sediment sampling in the mountain tributaries and the South Fork are plotted in Appendix 6-3. The relatively high levels of fines in the mountain stream samples are likely related to the recent landsliding in the basins associated with forestry activities (see Mass Wasting Assessment), and to the location of most of the samples on and near fans which are natural depositional areas. The levels of fine sediment in the South Fork, in contrast, may be lower than they once were (prior twentieth century) because of major modifications of the river channel that reduces the ability of the river to deposit sediment (see Section 6.5). However, all of the sediment samples collected undoubtedly suffer from small sample volumes and the limited number of samples collected. Larger sediment samples obtained from more locales may produce different results compared to what is reported in this study.

## 6.7 CHANNEL RESPONSE TO CHANGING INPUT VARIABLES

Channels located in different areas of the Acme WAU will respond differently to dynamic processes, such as sedimentation, flooding and changes in the supply of woody debris. Natural processes and forestry activities cause changes in the supply of wood and sediment to streams. This section describes generalized channel responses to variations in the supply of sediment, wood, and water. Predictions of response are based on historical information, general principals of mountain drainage basin geomorphology, and information contained in the channel and fish modules.

Channel responses are framed in terms of process, channel form, and magnitude and duration of effects. From the descriptions of channel geomorphic units (6.4) and the discussion of channel response to changing supplies of sediment, wood, and water (below), fishery biologists can define channel vulnerability ratings (e.g., high, moderate, and low) for use in the regulatory rule box. In addition, channel sensitivities classified into high, moderate, and low are contained in Appendix 6-4 (Form E-6), according to watershed analysis protocol.

**Channel Geomorphic Units 1 and 2** (mainstem South Fork Nooksack River and its floodplain; low-gradient ($<=$ 0.001), generally unconfined although diking and agricultural activities have confined the mainstem and isolated it from its floodplain)

Mass Wasting, Effects, and Duration (onsite): Very limited opportunity for direct deposition by mass wasting. Rapid erosion of deposits possibly with boulder lag forming. Woody debris delivered by mass wasting should be highly mobile (piece length less than channel width and lack of debris jams).

Variations in Sediment Supply, Effects and Duration (offsite): Sediment waves (or channel aggradation) could occur but concentrated mass wasting in the upper basin (i.e., outside of the WAU) would likely be required. During high sediment supply, braiding is likely in unconstrained reaches and side channels may form. Sediment waves may cause channel avulsions around debris jams, and jams may become abandoned. Substrate should fine with a passage of a wave (i.e., an increase in gravel, pebbles, and sand). Scour and fill may increase and could range between 0.5 and 2.0 m. However, all of these responses will be highly muted because at least 50% of the channel is diked which confines the flow and sediment transport to a single channel.

Variations in Wood Supply, Effects: Historically, the portion of the South Fork Nooksack in the Acme WAU contained a multi-mile long woody debris jam. Undoubtedly, large volumes of aquatic and riparian habitats were associated with this jam.

Woody debris, particularly in accumulations in jams, should have significant effects on channel and floodplain morphology. Jams may cause avulsions and the creation of secondary channels and mid-channel islands. During high sediment supply wood recruitment from banks may increase because of increased meandering. However, ongoing removal of woody debris for flood control and recreation (currently no channel spanning jams exist) does not allow for the accumulation of woody debris jams and associated morphological changes.

Effects of Flooding: The effects of flooding should be most significant when coupled with high sediment supply. Flooding can lead to braiding and the development of side channels, bank erosion and increased tree recruitment. Flooding may also cause channel avulsions to be concentrated around debris jams. Flooding linked with pulses of sediment may lead to fluctuations in sour and fill on the order of 0.5 and 2.0 m. However, flood-control diking has limited flooding (of the historical floodplain). In addition, because diking has restricted channel width, high rates of scour are more likely.

**Channel Geomorphic Units 3 and 4** (floodplain slough channels)

Mass Wasting, Effects, and Duration (onsite): Very limited opportunity for direct deposition of landslides and debris flows in existing slough channels. In general, not applicable.

Variations in Sediment Supply, Effects, and Duration (offsite): Secondary channels on the South Fork Nooksack floodplain form during large floods, often in conjunction with woody debris jams and high sediment supply. These flood – sediment – wood interactions must occur on relatively wide and unconstrained portions of the valley floor (i.e., within the active floodplain of the South Fork Nooksack River). Presently, the flood control dikes and removal of large organic debris precludes the formation of significant secondary channels.

Although secondary channels or sloughs can be filled in during movement of sediment or during channel anastomosing (linked to wood jams and/or floods) other slough channels may form nearby. Hence, fluctuations in sediment, wood, and flooding all contribute to the loss and development of slough channels over time in a naturally functioning floodplain channel.

Variations in Wood Supply, Effects: Because of low water velocities, woody debris should have significant and long-term effects in secondary or slough channels, including sediment storage and development of deep pools. Woody debris may also create sediment deposits that can isolate the slough channel from the mainstem.

Effects of Flooding: Flooding can be associated with the filling in of slough channels with sediment but also in the development of those channels (see above). Presently, most flooding is confined to the main channel because of diking.

**Channel Geomorphic Unit 5** (alluvial and debris flow fans).

Mass Wasting, Effects, and Duration (onsite): Many of the fan segments can be impacted directly by debris flows or dam-break floods. Debris flows can deposit unsorted, fine-grained, matrix-supported sediment up to 0.3 to 2 meters thick on fans. Burial of existing channels or habitats is highly likely with formation of new channels occurring following stream incision of the deposits. Although dam-break floods are comprised mostly of water and organic debris, they can scour existing channel features (and habitats) on fans. Loss of habitat in either case would be significant.

Variations in Sediment Supply, Effects, and Duration (offsite): Waves of sediment (or channel aggradation) should occur following mass wasting in the upper basin or following debris flows or dam-break floods. Sedimentation can bury existing habitats. Sedimentation may result in increased bank erosion (tree recruitment), the formation of secondary channels and channel anastomosing where channels may take a different path down the fan. Periods of aggradation may persist for years and possibly up to a decade. Step pool and cascade morphology should be associated with low sediment supply conditions (most likely condition).

Variations in Wood Supply, Effects: Wood jams would cause local and transient channel changes such as upstream sediment deposition, formation of small terraces, and deep pools that may persist for a few years; lack of wood leads to coarser substrate and bedrock.

Effects of Flooding (on channel form): Likely negligible during times of low sediment supply and high roughness; increasing scour with increasing sediment supply and with a finer substrate; decreasing channel lateral stability with decreasing amounts of wood. Comments: Aggradation on the Jones Creek fan may attain 5 meters or more based on historical deposits.

**Channel Geomorphic Unit 6** (tributaries with upland drainages generally located below Unit 5).

Mass Wasting, Effects, and Duration (onsite): Generally outside the range of debris flow or dam-break deposition. Deposition of mobile mass movements should occur in the segment upstream (Segment 5 - alluvial/debris fans).

Variations in Sediment Supply, Effects, and Duration (offsite): Periods of aggradation are very likely following mass wasting in the tributary valleys or following deposition of debris flows (or dam-break floods) on the alluvial/debris flow fan immediately upstream. Aggradation may vary between 0.5 and 1.5 meters and persist for a few years to a decade). A cycle of aggradation and degradation associated with high sediment supply should form small terraces. Silt and clay should be transported as washload and in general should not be well represented in the bed and bars. The proportion of sand (particles less than 2 mm but greater than 0.06 mm) should increase in the channel bed during periods of aggradation.

Channel morphology under low sediment (and wood) supply should be dominated by cobbles and small boulders. A step pool and cascade morphology would dominate. During high sediment supply, the proportion of cobbles and gravel beds may increase for a short period of time. At certain locations, channel aggradation would result in gravel beds, although they should be transient.

Variations in Wood Supply, Effects: Wood jams may cause major local channel changes such as gravel deposits upstream, short and discontinuous terraces, and the formation of pools. Spawning gravel and pool frequency and depth should increase with increasing woody debris.

Effects of Flooding (on channel form): Flooding can result in scour in these typically well defined channels, particularly during periods of higher sediment storage (aggradation) and low wood storage. The relative effect of flooding is high compared to the alluvial fan segment or the mountain channel.

**Channel Geomorphic Unit 7** (steep mountain tributaries).

Mass Wasting, Effects, and Duration (onsite): All of these segments can be impacted directly by landslides and debris flows. Accumulation of thick deposits of sediment (greater than 2 - 4m) particularly behind wood jams (also formed by mass wasting) is likely. Deposits may persist for decades, depending on the longevity of the wood jams. Landslide and debris flow deposits may also result in dam-break floods. Dam-break floods or migrating organic dams can be routed through entire lengths of these mountain channel segments causing widespread scour and disruption of the channel, valley floor and inner gorge. Post dam-break flood inner gorge landsliding is likely.

Burial or removal of existing channels or habitats is highly likely following major mass wasting in these channels. A dam-break flood can scour existing channel features (and habitats). Loss of habitat in either case would be significant.

<u>Variations in Sediment Supply, Effects, and Duration (offsite)</u>: Waves of sediment (or channel aggradation) can occur in these channels following mass wasting in the upper basin or following debris flows or dam-break floods. Sedimentation can bury existing habitats. Sedimentation may also result in increased bank erosion (tree recruitment) and the formation of limited secondary channels; periods of aggradation may persist for years but probably less than a decade because of high transport capacity. Step pool and cascade morphology should be associated with low sediment supply conditions (most likely condition).

<u>Variations in Wood Supply, Effects</u>: Wood jams would cause local and transient channel changes such as upstream aggradation, formation of small terraces, and deep pools that may persist for a few years to a decade or longer; lack of wood leads to coarser substrate and bedrock and lower pool frequency. Wood probably plays a lesser role compared to lower-gradient and wider channels where there is less boulders and bedrock.

<u>Effects of Flooding (on channel form)</u>: Likely negligible during times of low sediment supply and high roughness. Floods should cause increasing scour and disruption of habitat with increasing sediment supply and decreasing woody debris.

## 6.8 HABITAT FORMING PROCESSES

A description of habitat forming processes in the South Fork Nooksack River (and its floodplain - the slack water slough channels) is contained in Section 6.5 and a brief summary can be found in 6.8.5. In the mountain tributaries, the majority of the potential anadromous habitat is located below the alluvial/debris fans in the channel segments on the Nooksack floodplain (see Fisheries Assessment). The low gradient of the floodplain allows gravels to deposit in the lower reaches of the mountain tributaries which creates spawning areas and low velocity water suitable for pools to form. In addition, riparian forests contribute woody debris to these small channels which is important in the creation of gravel storage areas, pools, cover and habitat complexity.

## 6.9 ANSWERING CRITICAL QUESTIONS

The complete answers to the critical questions can be found in the preceding discussion including the figures and appendices. The following is a brief summary of those answers.

### 6.8.1 *What is the spatial distribution of channel response types?*

Refer to Figure 6-2. All channel segments are responsive to changes in sediment, water and woody debris. The mountain tributaries (Segments 6 and 7) and their fans (Segment 5) respond to debris flows, dam-break floods and accelerated sediment supply from mass wasting. Many of the fans (mapped in Figure 6-2) are susceptible to debris flow and dam-break floods. Other alluvial fans, such as Tinling Creek, are responsive to increases or decreases in bed material supply (i.e. aggradation and degradation). Both mountain tributaries and channels on fans will change bed morphology in response to the addition or loss of woody debris; the fan segments may be most sensitive.

The South Fork Nooksack River and its floodplains are responsive to sediment influxes from upstream and from woody debris. Refer to Section 6.5 for a discussion of the extensive modifications that have been made to the South Fork.

6.8.2 *Is there evidence of channel change from historic conditions?*

South Fork of the Nooksack River: Refer to Section 6.5 for a complete discussion of these changes, the following is a summary. The South Fork of the Nooksack River was characterized historically (as late as 1938) by a highly sinuous and meandering channel that contained many braided reaches, and by an active and large floodplain containing numerous gravel bars. The South Fork channel contained many large log jams throughout its length in the Acme WAU. Numerous low velocity slough channels existed on the floodplain. The South Fork River and its floodplain provided extensive spawning habitat. In particular, the numerous slough channels and backwater areas of the lower Nooksack River would have supplied major rearing habitat for juvenile salmonids that would have been displaced by winter floods from the steeper mountain channels upstream in the South Fork watershed. Hence, the lower South Fork Nooksack in the Acme WAU may have functioned as critical refuge habitat for the entire South Fork basin.

Mapping of river channels in 1885 and 1938 indicates the degree to which the morphology of the river and its floodplains have been altered by 1994. Approximately 60% of the length of the South Fork has been diked. Diking is mostly confined to the outside of meander bends which limits the ability of the river to meander across its floodplain and create gravel bars (point bars). Hence, there has been a 40% decrease (since 1938) in the area of gravel bars. The almost complete elimination of secondary channels (braids) has caused a 35% reduction in channel length. Agricultural practices have caused an 86% reduction in slough channels on the South Fork floodplain. One hundred percent of channel-spanning log jams have been removed, and a 50% reduction in sharp-angled ($>60^0$) meander bends has occurred. The result of all these river and floodplain modifications is that the river no longer has access to its extensive floodplain, and hence has been converted to a simple conduit for the routing of sediment and water. The quality spawning and rearing habitat has been virtually eliminated in the South Fork within the Acme WAU. In addition, the loss of sediment and flood storage implies that sedimentation and flooding problems may be exacerbated downstream of the Acme WAU.

Mountain Tributaries: The mountain tributaries (i.e. Sygitowicz, McCarty, and Jones Creeks etc.) historically provided much less fish habitat compared to the South Fork and its floodplain (see Fisheries Assessment). Nevertheless, there have been substantial changes to these systems because of logging, farming and urbanization. Debris flows and dam-break floods, many of them triggered by forestry practices since the 1950s in some of the tributaries (refer to Mass Wasting Assessment for the complete inventory of events), have removed dispersed in-channel woody debris and caused severe aggradation in the lower portions of the channels. Loss of woody debris should have reduced the frequency and depth of pools in the mountain tributaries but lack of prior data does not allow us to quantify the loss. Mass wasting has also resulted in elevated levels of fine sediment in stream gravels and probably a loss of pools. Farming and urbanization (Acme) on the Nooksack floodplain have led to a reduction of riparian forests along some of the tributaries and to dredging of channels to minimize flooding.

### 6.8.3 *What do existing channel conditions indicate about past and present active geomorphic processes?*

<u>South Fork Nooksack River:</u> The fluvial geomorphology of the South Fork Nooksack River in the Acme WAU in 1991 has been altered because of channel modification. River maps from 1885 and 1938 provide evidence that sediment deposition led to a highly sinuous and braided channel morphology with numerous gravel bars. In addition, abandoned secondary channels on the floodplain created numerous low-velocity slough channels. Periodic flooding of the floodplain supported extensive wetlands and riparian forests. The low gradient of the river also contributed to the formation of extensive woody debris jams.

<u>Mountain Tributaries:</u> Many of the steep, mountain tributaries (such as Sygitowicz, Standard, McCarty and Jones Creeks) produce debris flows and dam-break floods. In the small mountain tributaries, sediment supply is typically less than sediment transport capacity (sediment limited conditions) and the channel is consequently often floored in bedrock and large substrate (i.e. boulders and cobbles). The sediment limited condition is occasionally punctuated by brief periods of high sediment supply when channels may become gravel bedded. In addition, during periods of erosion in the subbasins the lower portions of mountain tributaries on the Nooksack floodplain, including the alluvial/debris fans, will aggrade. Following a lowering of sediment supply, the channels should mine their beds and expose coarser sediments and channel bedrock.

Landslides and blowdown are contemporary processes delivering woody debris to mountain tributary channels that create pools and local gravel storage sites. Debris flows and dam-break floods remove dispersed woody debris from streams thereby lowering pool frequency and depth.

### 6.8.4 *What are the likely responses to channel reaches to potential changes in input factors?*

South Fork Nooksack River: Low channel gradients, variations in sediment supply and periodic flooding were responsible for the highly sinuous, braiding character of the river prior to about 1940, including the formation of slough channels, extensive gravel bars, and log jams. Although a few of these river characteristics remain today, the river has been diked to limit the ability of the river to create multiple channels, inundate its floodplain and create log jams. Hence the South Fork is much less likely to respond to changes in input factors (water, sediment and wood) because of the human modifications. In addition, woody debris is typically removed from the river to eliminate the formation of large log jams, and slough channels have been filled in.

Mountain Tributaries: Many landslides, debris flows, and dam-break floods have been triggered by forestry activities during the last 40 years in the mountain tributaries of the Acme WAU. Debris flows and dam-break floods that travel through the tributaries remove dispersed woody debris and cause temporary channel aggradation. Streamside landslides can also contribute trees to the channel. On the tributary fans and floodplain of the Nooksack, increased sediment supply can lead to channel aggradation (coarse and fine sediment) and channel anastomosing, and during these periods tributary channels can leave their banks and travel across the floodplain. Woody debris can create pools and trap gravels, while an absence of woody debris can lead to fewer and shallower pools (such as the current condition). The effect of increased flooding (from rain-on-snow) probably varies with sediment supply. At low supply, the well-armored channels resist sediment transport and increasing floods may have little effect. However, with increasing sediment supply, increased floods may lead to increasing sediment transport.

Alluvial/debris flow fans - Natural Hazard Areas: Debris flows and dam-break floods can impact upper reaches of fans with logs and sediment, including boulders. Lower reaches of fans can aggrade more than one meter with fluvial sediment when large landslides or debris flow occur in the watershed. All of the fans at the base of most of the mountain tributaries should be considered high hazard areas, although they were not mapped as part of this watershed analysis.

### 6.8.5 *What are the dominant channel- and habitat-forming processes in different parts of the channel network?*

South Fork Nooksack River: Refer to 6.5 for more details. The principal channel- and habitat-forming processes in the South Fork Nooksack in the Acme WAU is the interaction of the river with its floodplain. The ability of the South Fork to meander and braid extensively across its floodplain creates gravel storage areas that provide spawning habitat, large log jams that provide stability to the gravel bars and provide habitat cover and complexity, and low-velocity slough channels that provide critical winter refuge habitat for the entire South Fork watershed. To maintain this important fish habitat, it is important to have episodic flooding, high sedimentation rates (a consequence of a low channel gradient and an actively eroding watershed), and a supply of drifting large trees (entering the river from bank erosion and landsliding).

Mountain Tributaries: The delivery of sediment, including boulders and whole trees by mass wasting along the steep inner-gorge areas is an important habitat-forming process in the steep mountain channel segments. The regime of mass wasting is important, defined by frequency, magnitude and spatial distribution; the natural mass wasting regime is not known for the Acme WAU. Besides landslide recruitment, other mechanisms of tree recruitment into steep channels, such as blowdown, are also important habitat processes.

The storage of sediment on fans and the recruitment of woody debris by blowdown are important habitat processes. The location of the lower mountain tributary channel segments on the Nooksack floodplain allow for deposition of gravel, and lower velocity water, necessary for spawning and rearing. The most important habitat contained in these tributaries is located on the Nooksack floodplain.

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# APPENDIX 6-1

Appendix 6-1 Review of discretionary procedures allowed when conducting a Level 2 channel assessment.

## ANALYSIS PROCEDURE

Level 2 teams are expected to produce similar assessment products augmented by additional information for specific situations. This may include specific analyses of particular processes or sub areas within the watershed. In addition, to facilitate the scientific review of assessment products, **the format for presentation of results shown in the channel assessment report section must be followed <u>when standard assessment forms are not used by Level 2 teams</u>**. pp. E-10 & E-11

## CLASSIFY SEGMENTS

Although some judgement is required to delineate segments, **the following criteria are suggested as a guide.** pp.E-14

## CURRENT CHANNEL CONDITIONS

Although methods are provided here, **the analyst may use discretion in the detail and methods employed to characterize key features.** Although these characteristics are appropriate indicators of channel conditions, **not all are relevant and need to be measured in each channel segment.**

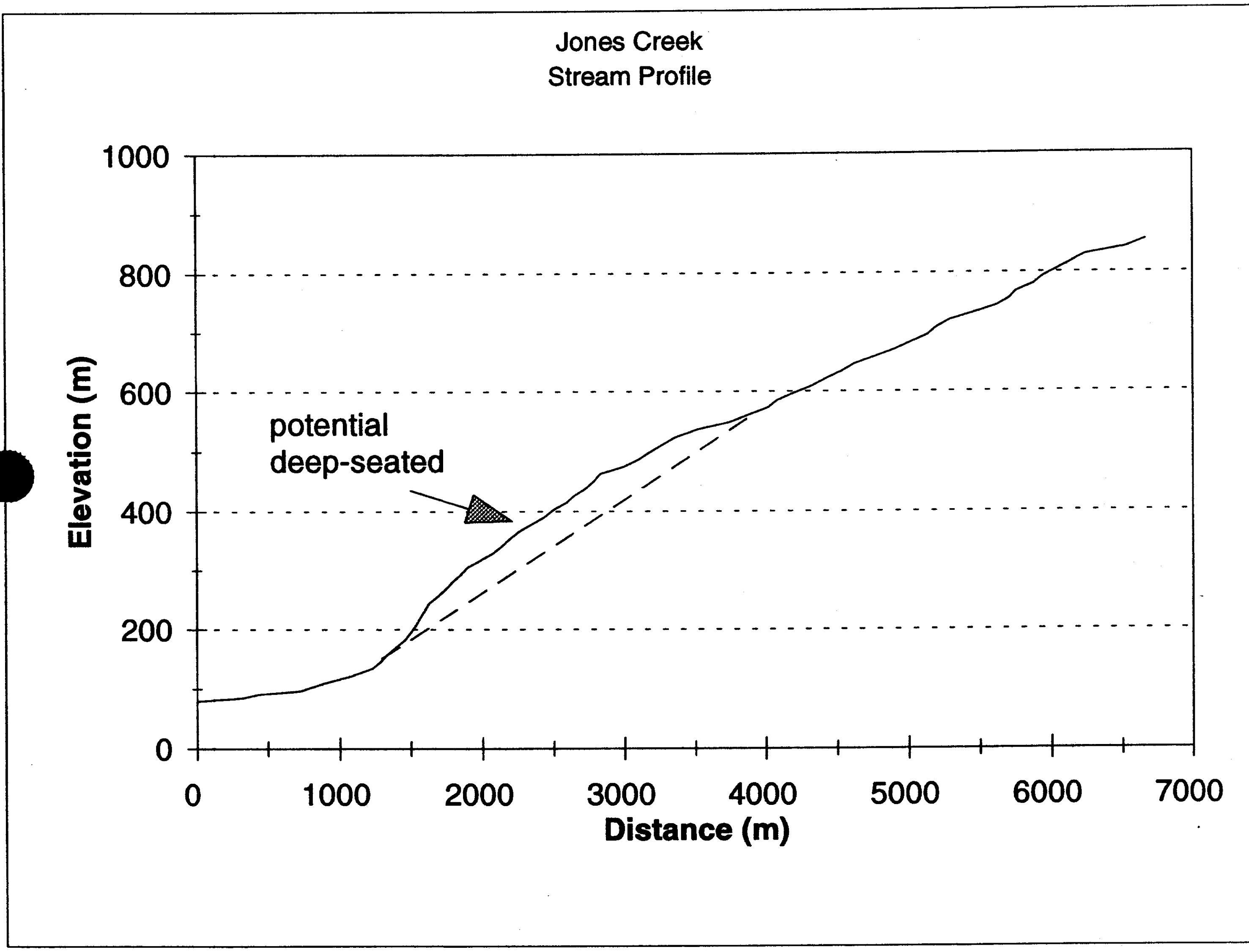
The field measurements and observations described below is a list of **tools that can be used to interpret stream channel conditions. If other scientific methods are used, they need to be fully explained in the channel assessment report.** pp. E-28 & 29

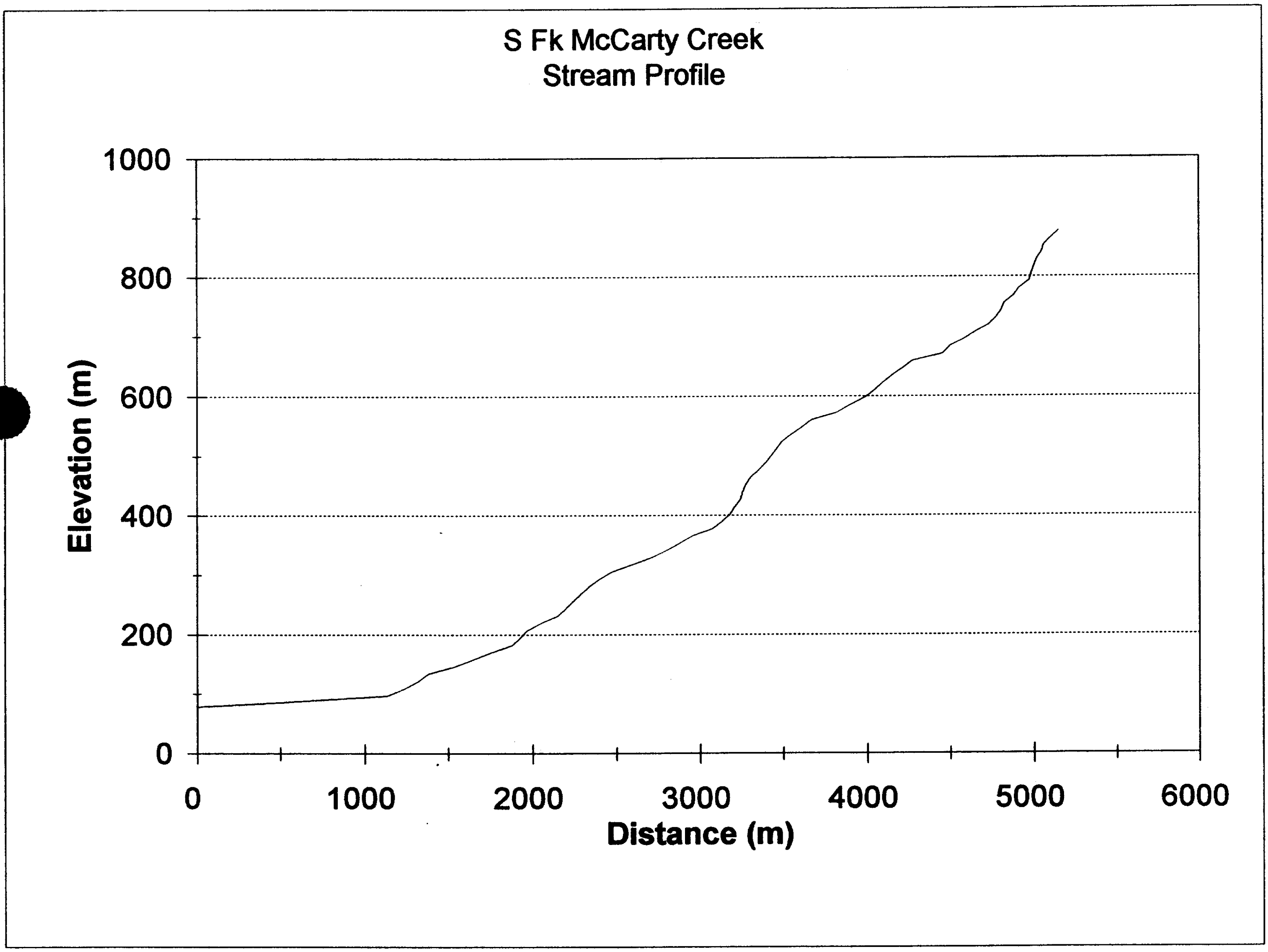
## CHANNEL SENSITIVITY INTERPRETATION

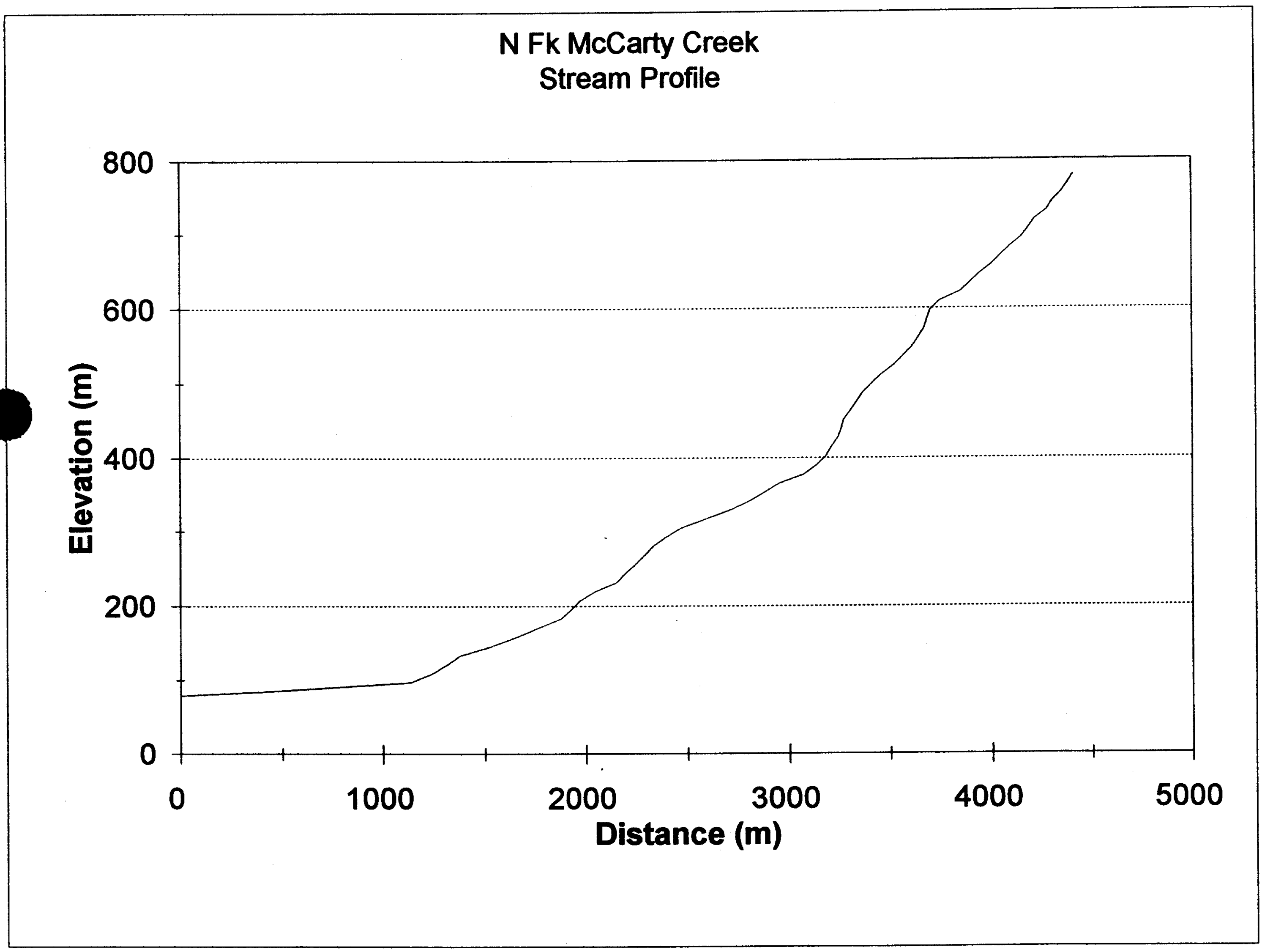
In essence, the **analyst customizes the interpretation** of response originally based on the response matrix (Table E-2) for a particular watershed location in question. **This step is crucial if the analyst is to develop an interpretation of channel processes tailored to the watershed under study.** Performing this step **relies on the analyst's experience and expertise.**

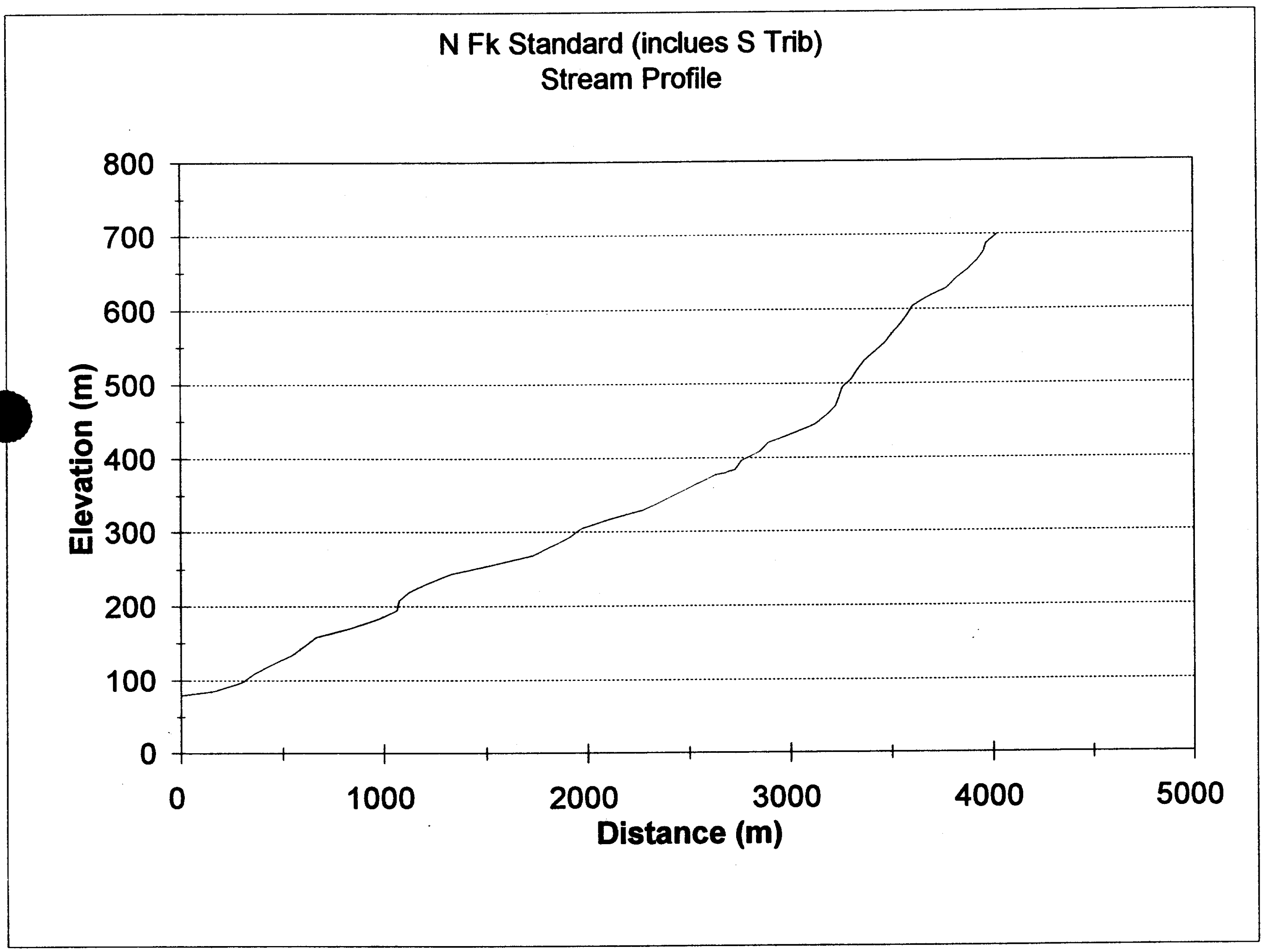
Although the generalized response table provides a good starting point for the assessment, **simply parroting its interpretations as conclusions of the analysis yields no insight into the watershed** under study since the table cannot account for geologic materials and local situations. Failure to adjust the response table for the geomorphic unit in question will result in low confidence in the analysis.

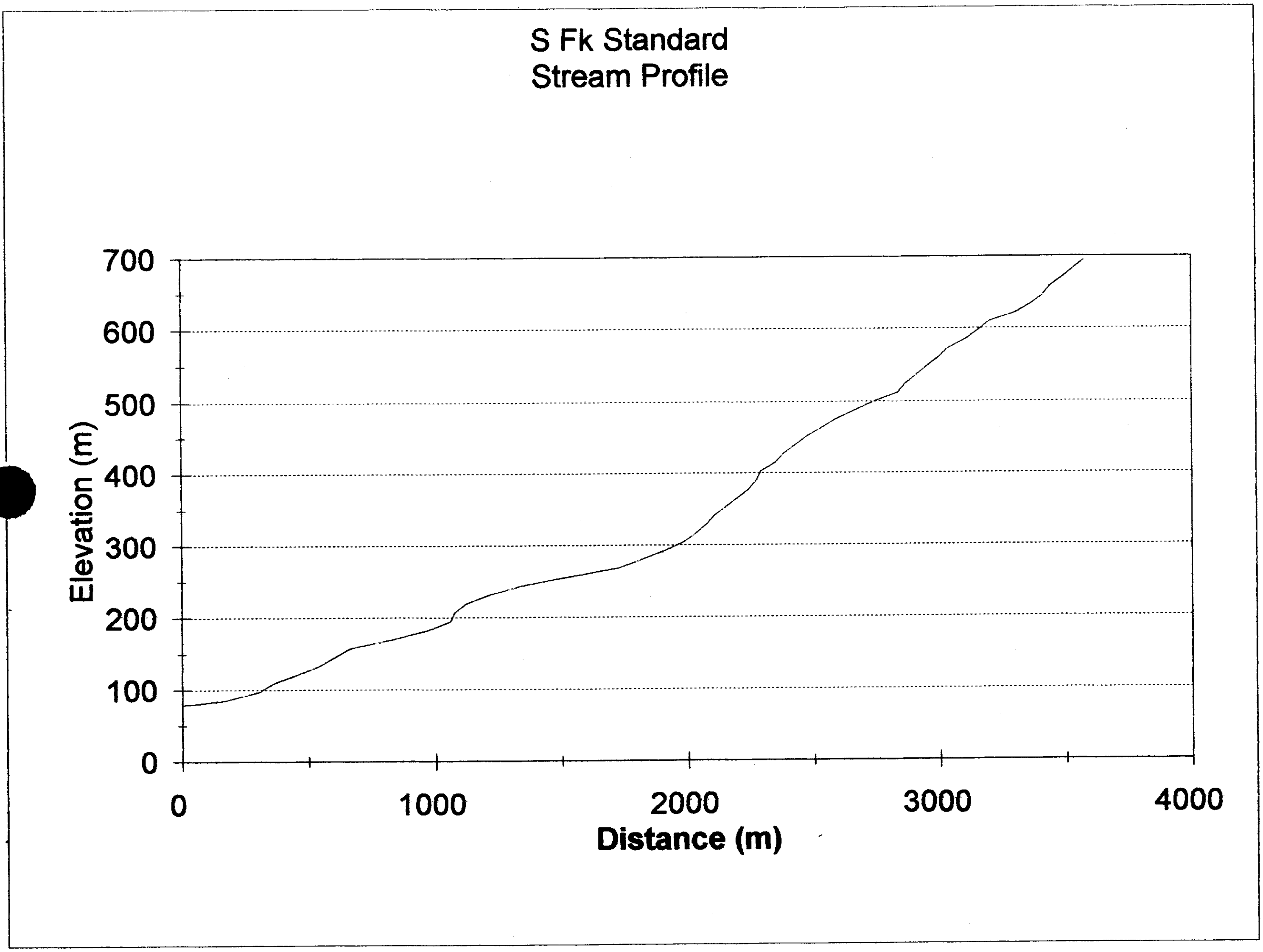
# APPENDIX 6-2
# LONGITUDINAL PROFILES


Jones Creek
Stream Profile
1000
800
600
400
200
0
Elevation (m)
potential
deep-seated
0
1000
2000
3000
4000
5000
6000
7000
Distance (m)

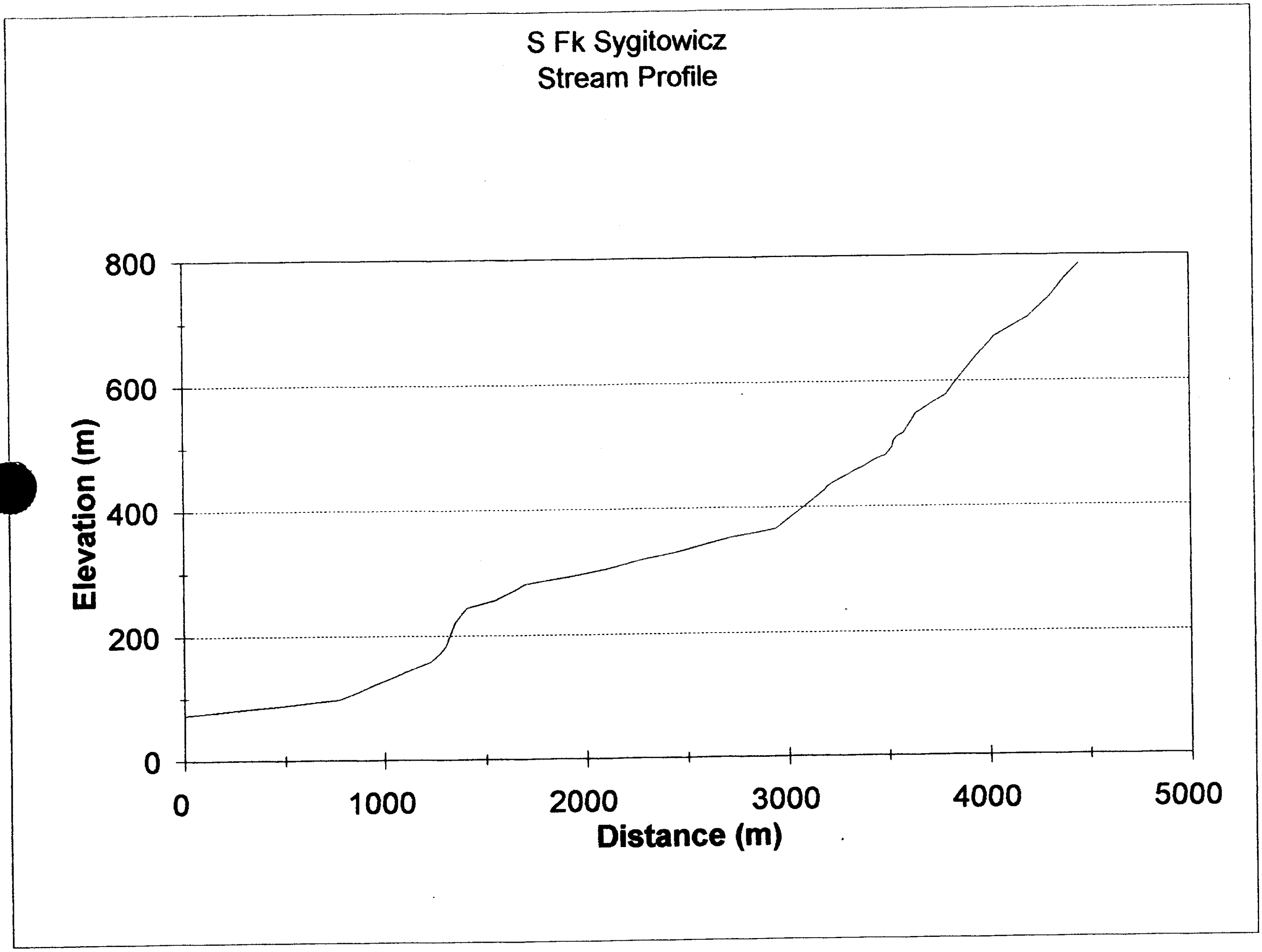

S Fk McCarty Creek
Stream Profile
1000
800
600
400
200
0
Elevation (m)
0
1000
2000
3000
4000
5000
6000
Distance (m)

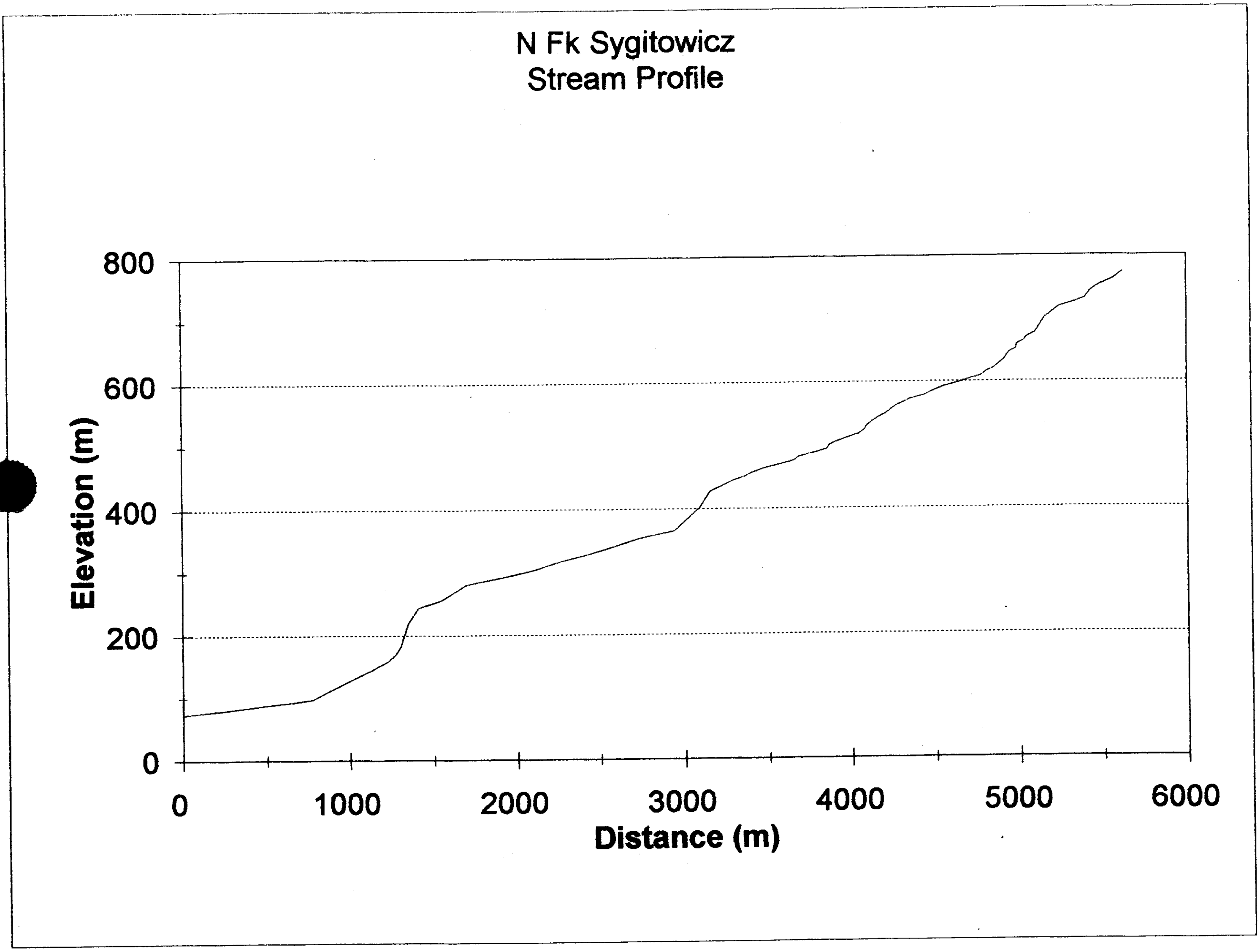

N Fk McCarty Creek
Stream Profile
Elevation (m)
800
600
400
200
0
0
1000
2000
3000
4000
5000
Distance (m)


N Fk Standard (inclues S Trib)
Stream Profile
800
700
600
500
400
300
200
100
0
Elevation (m)
0
1000
2000
3000
4000
5000
Distance (m)



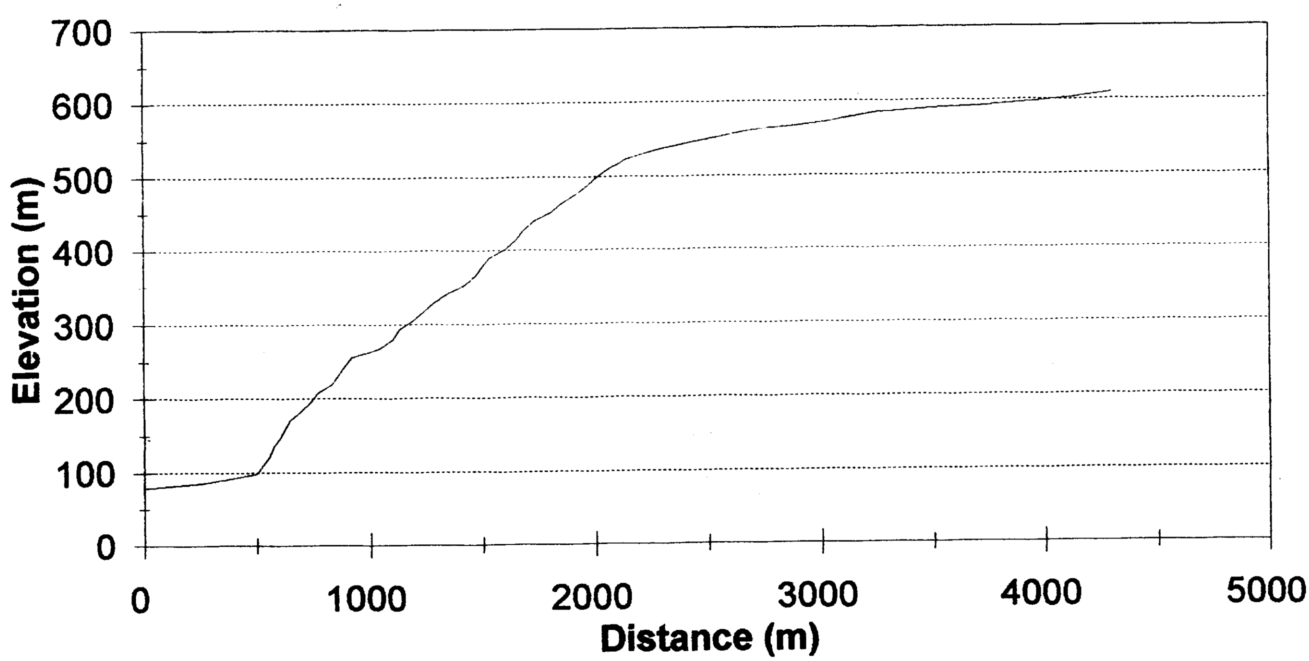
S Fk Standard
Stream Profile
Elevation (m)
Distance (m)
0
100
200
300
400
500
600
700
0
1000
2000
3000
4000


S Fk Sygitowicz
Stream Profile
Elevation (m)
800
600
400
200
0
0
1000
2000
3000
4000
5000
Distance (m)

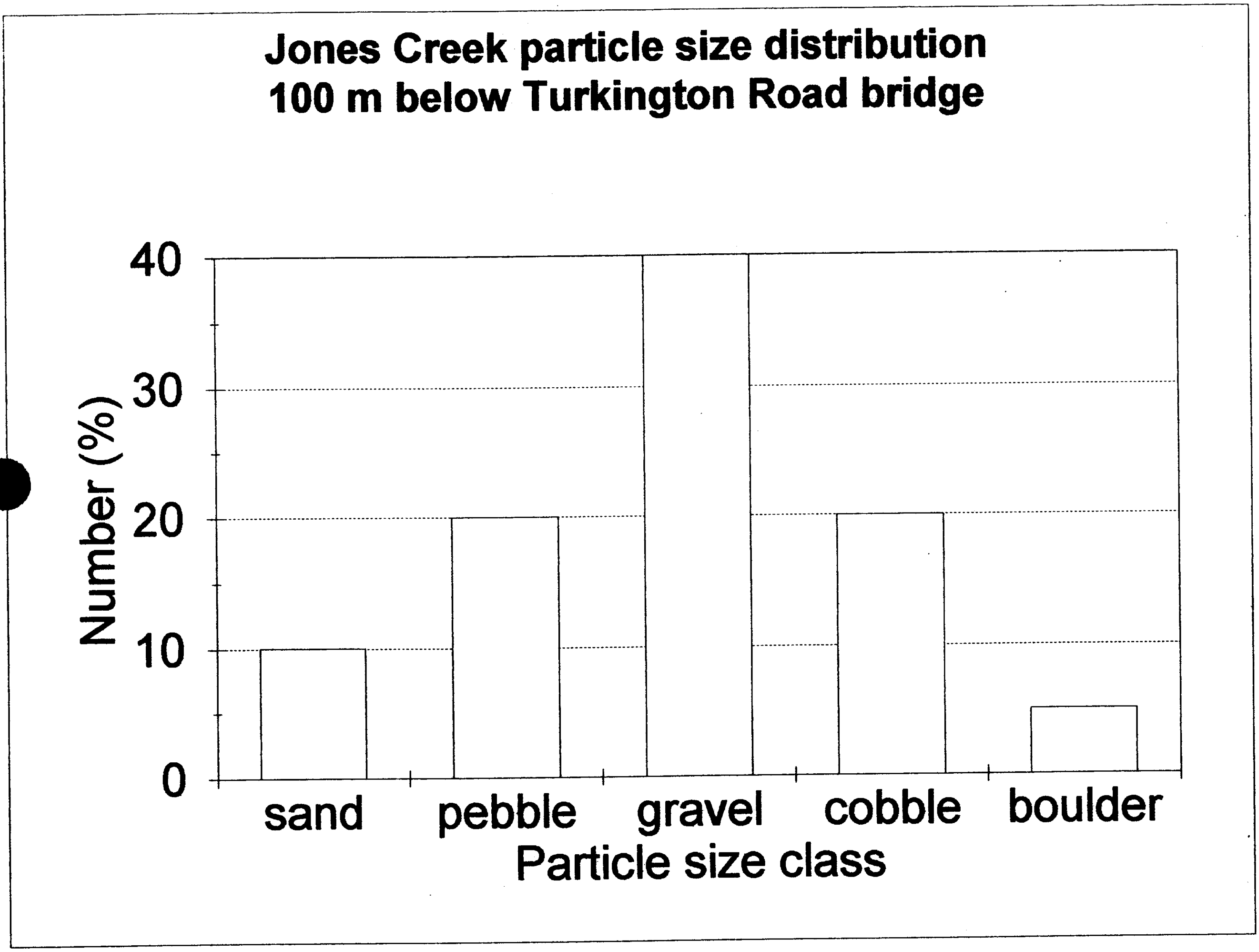


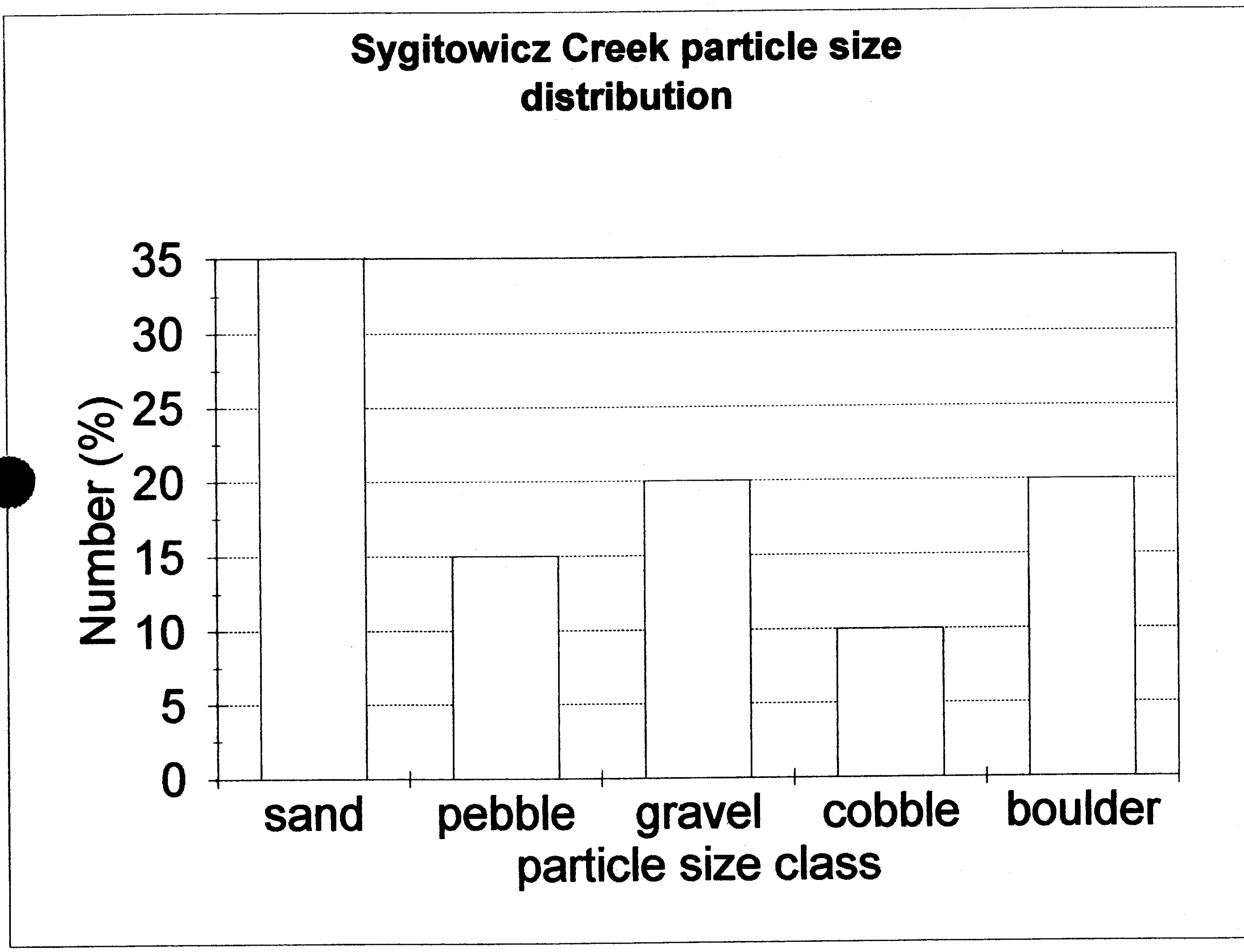
N Fk Sygitowicz
Stream Profile
Elevation (m)
800
600
400
200
0
Distance (m)
0
1000
2000
3000
4000
5000
6000

Tinling Creek
Stream Profile

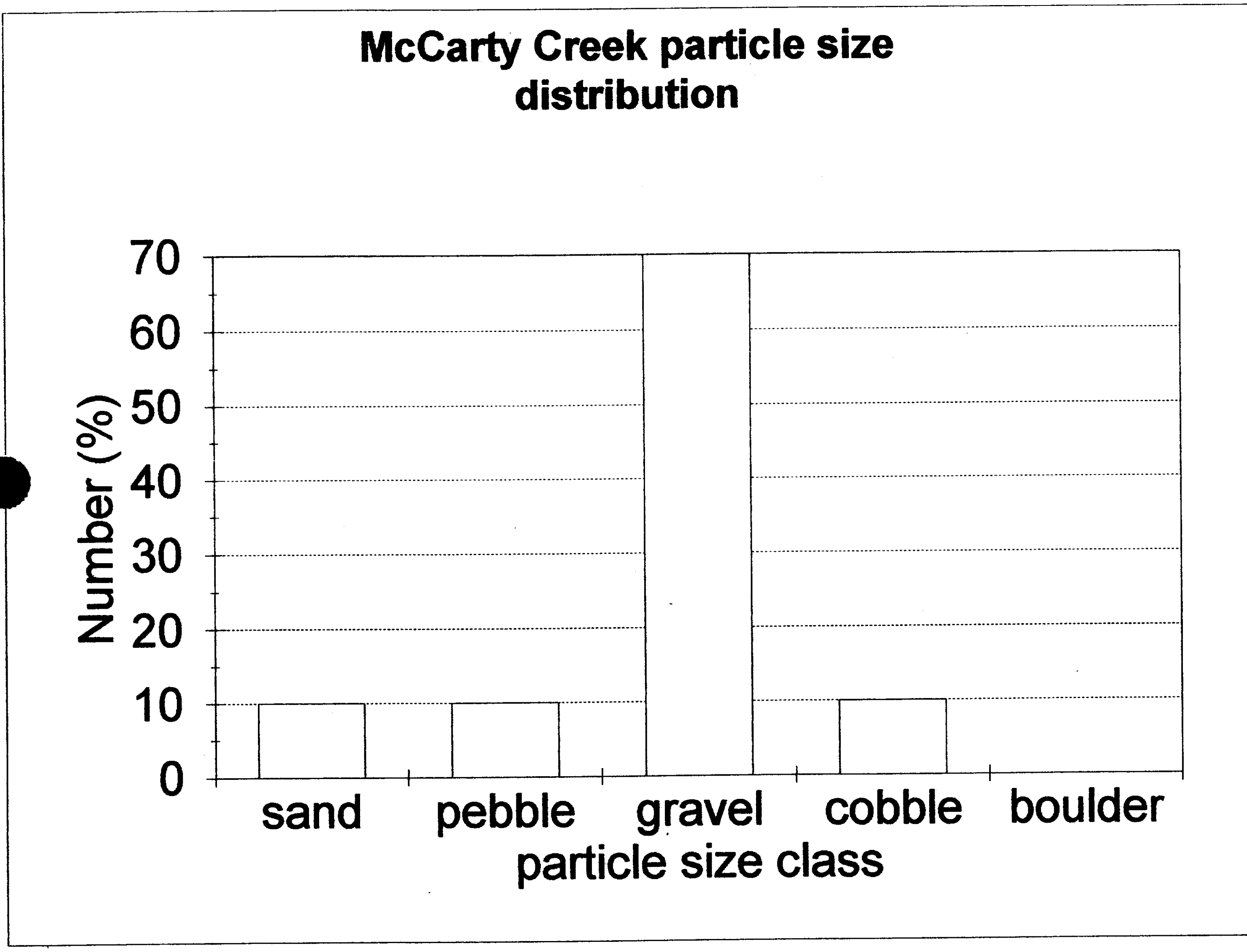


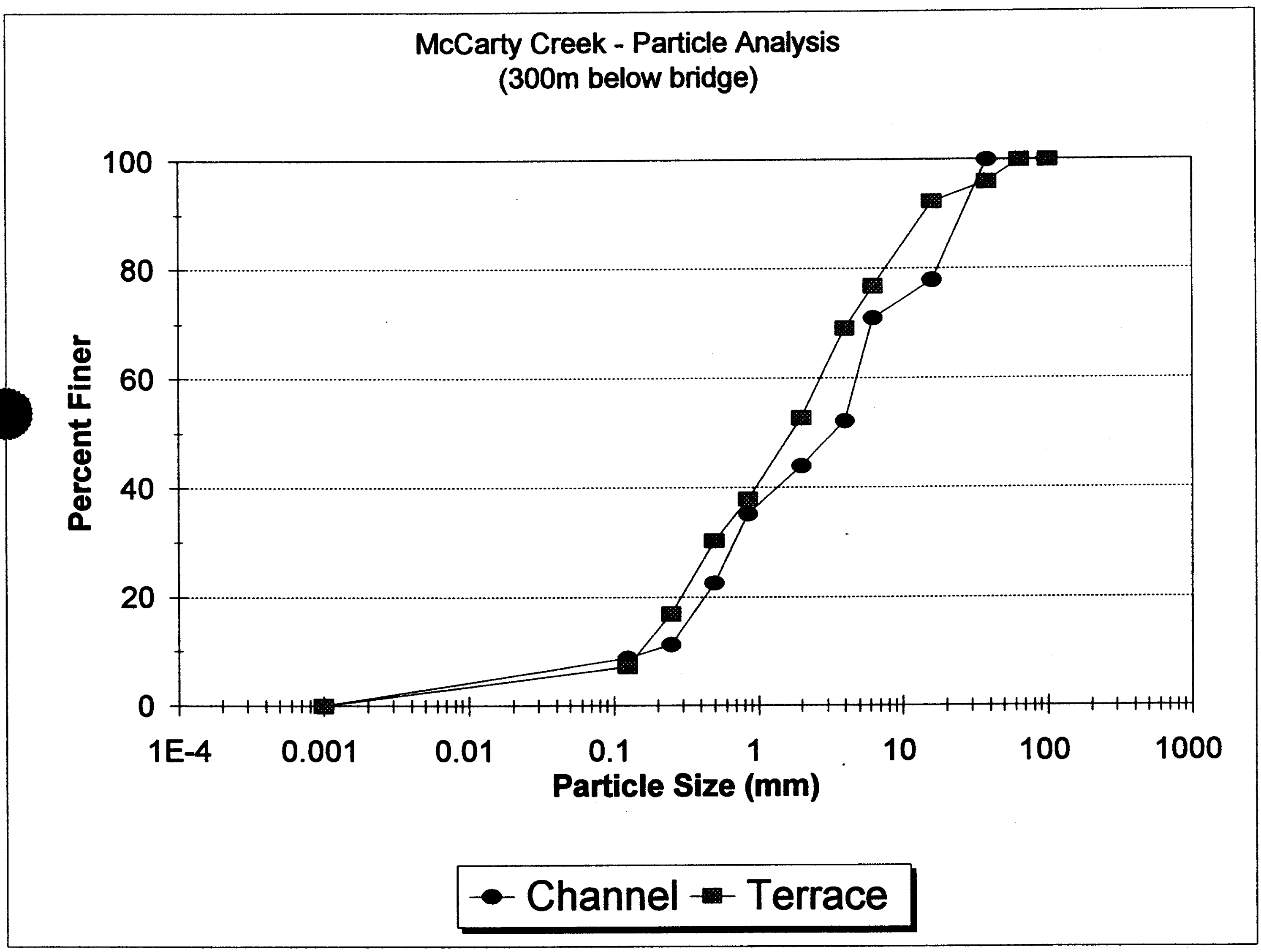
# APPENDIX 6-3
# PARTICLE SIZE ANALYSES

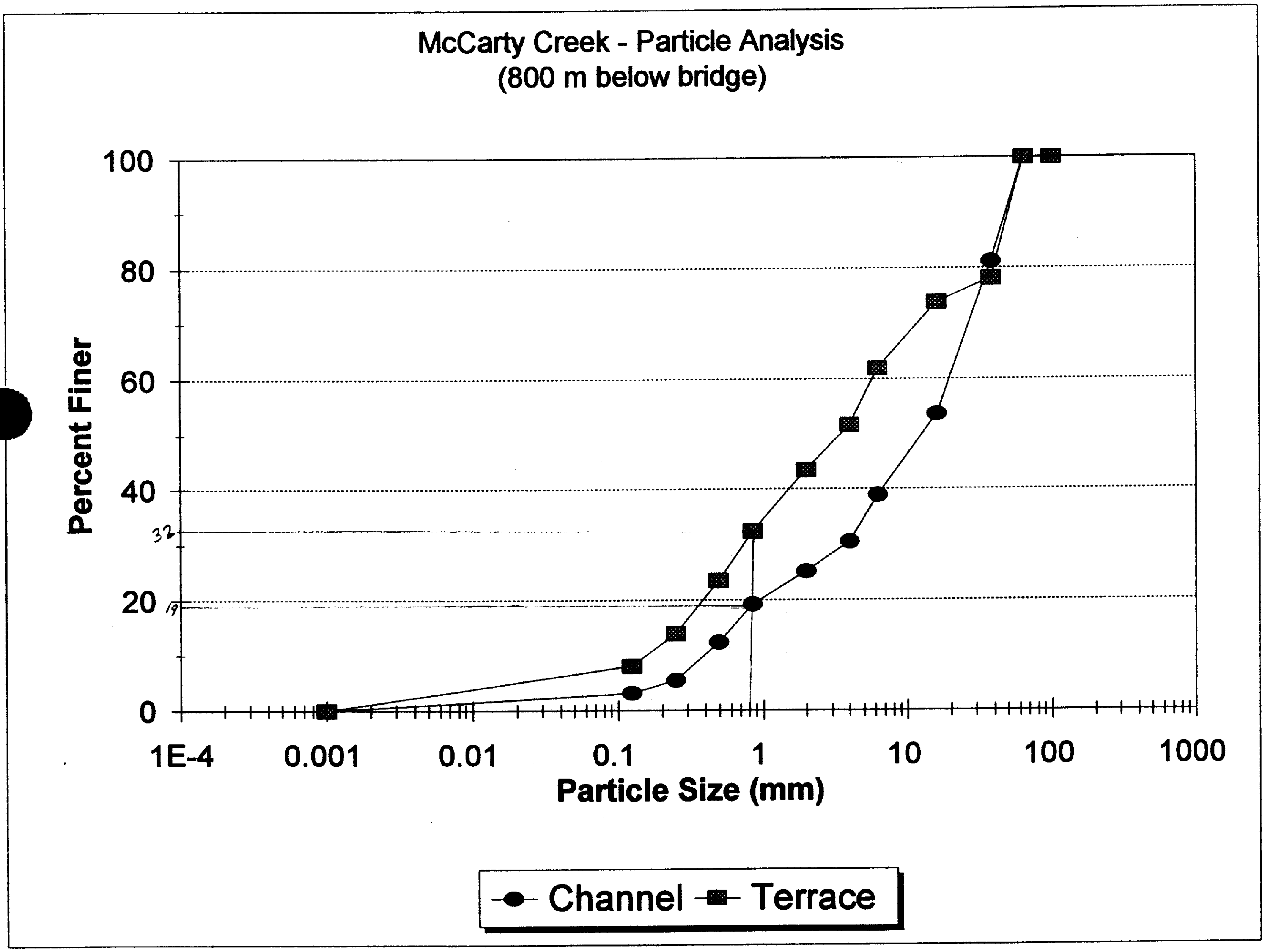

Jones Creek particle size distribution
100 m below Turkington Road bridge
40
30
20
10
0
Number (%)
sand
pebble
gravel
cobble
boulder
Particle size class



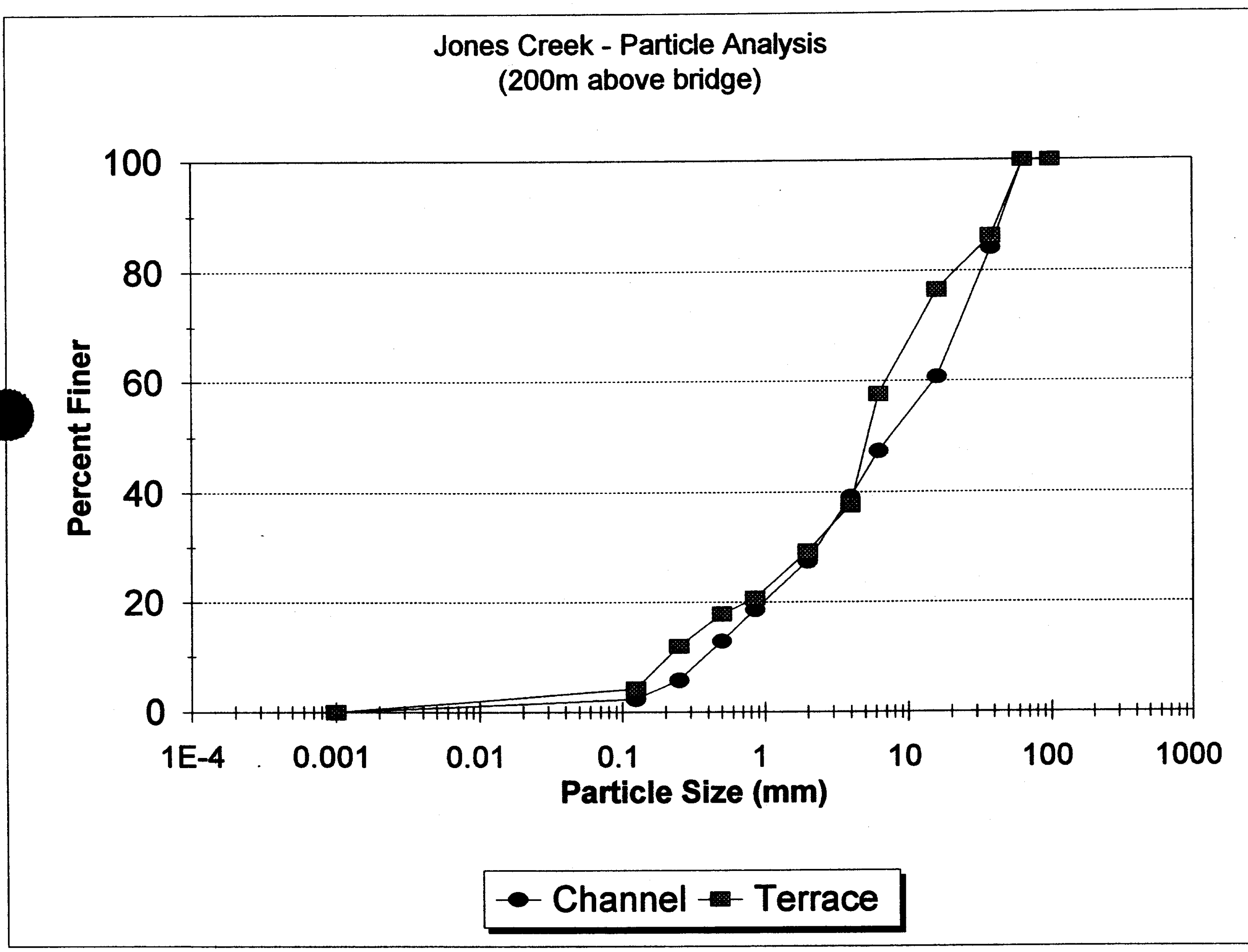
Sygitowicz Creek particle size distribution
Number (%)
0
5
10
15
20
25
30
35
sand
pebble
gravel
cobble
boulder
particle size class


McCarty Creek particle size distribution
Number (%)
0
10
20
30
40
50
60
70
sand
pebble
gravel
cobble
boulder
particle size class

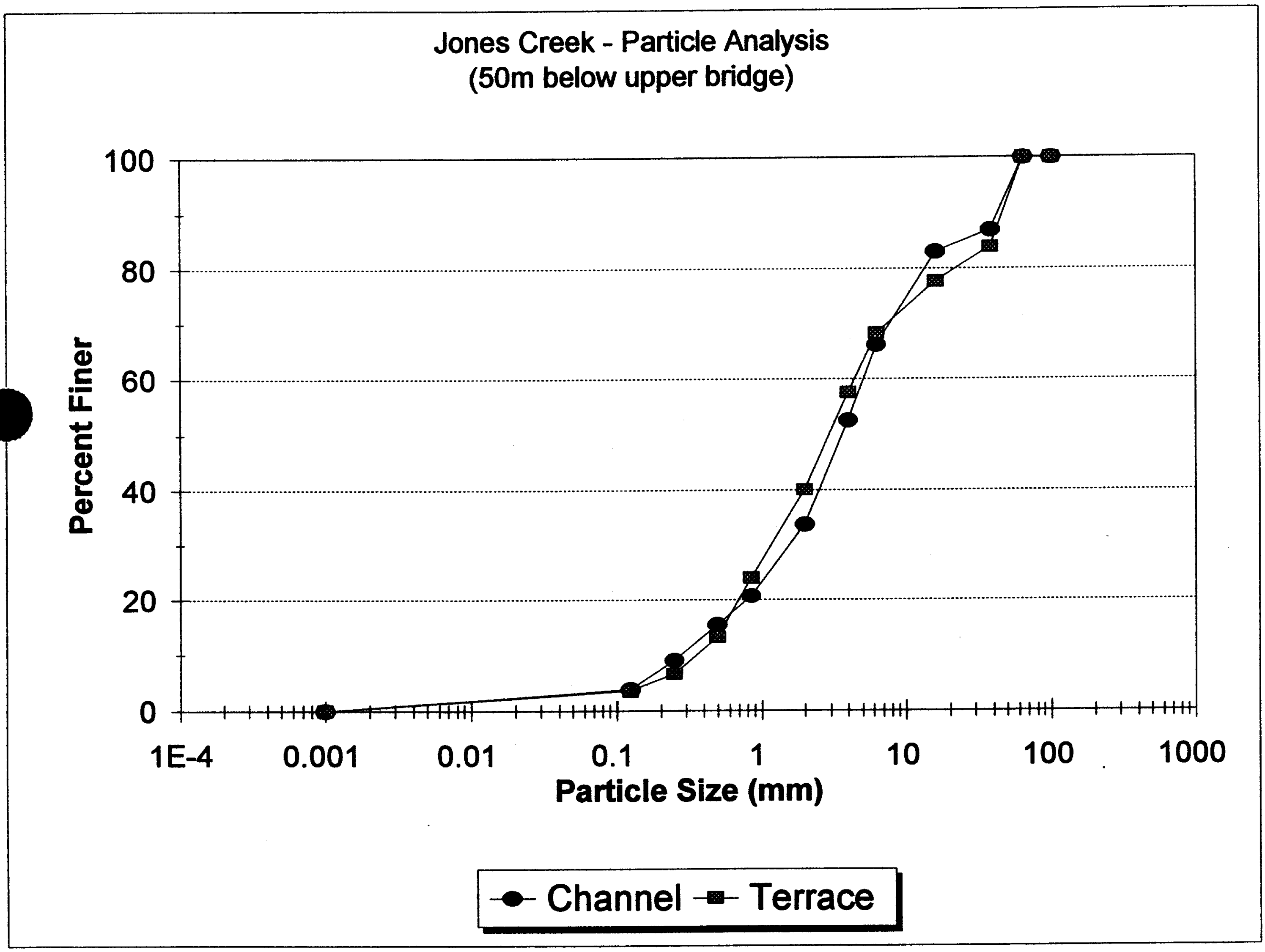

McCarty Creek - Particle Analysis
(300m below bridge)
100
80
60
40
20
0
Percent Finer
1E-4
0.001
0.01
0.1
1
10
100
1000
Particle Size (mm)
Channel
Terrace

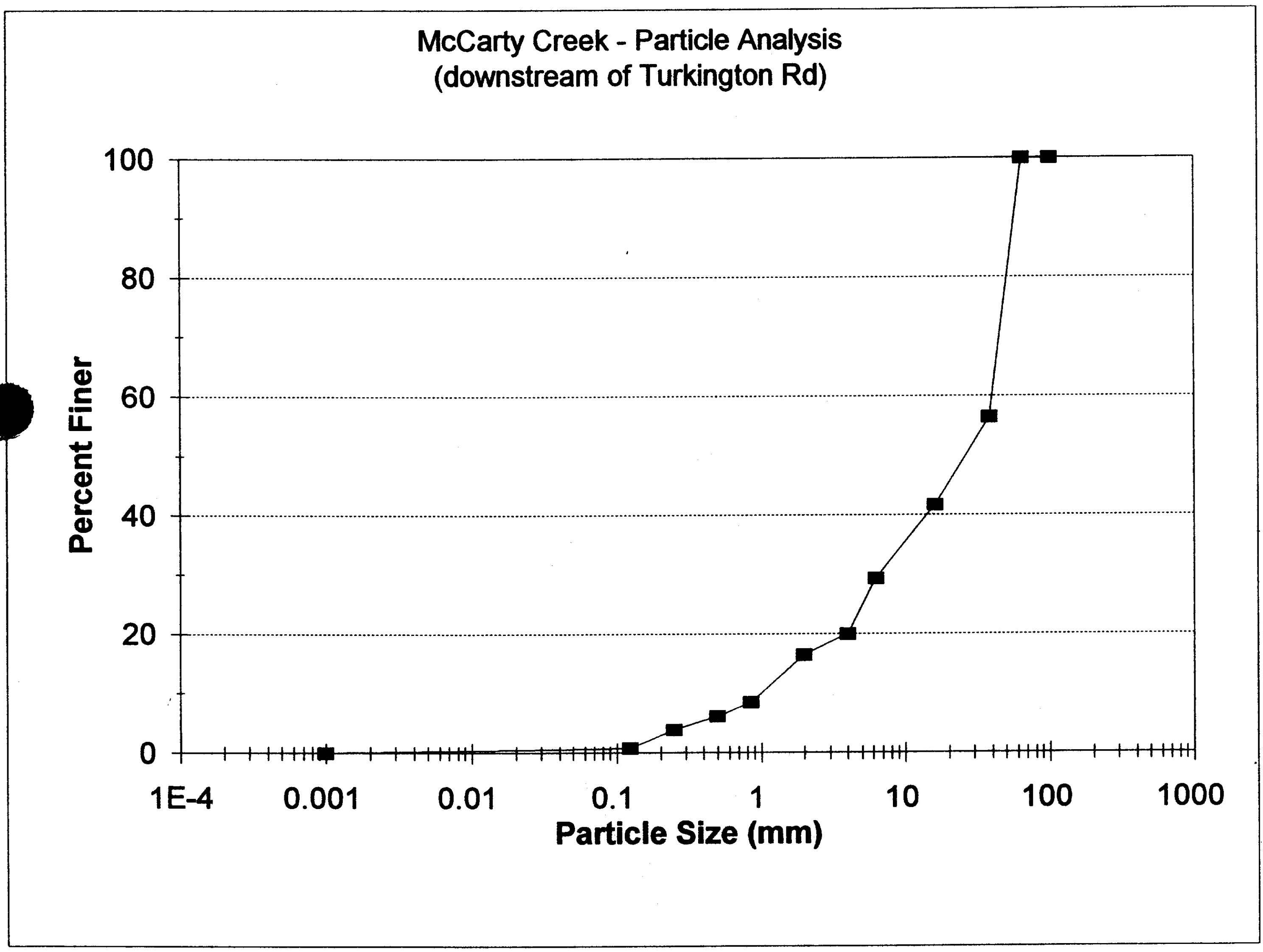


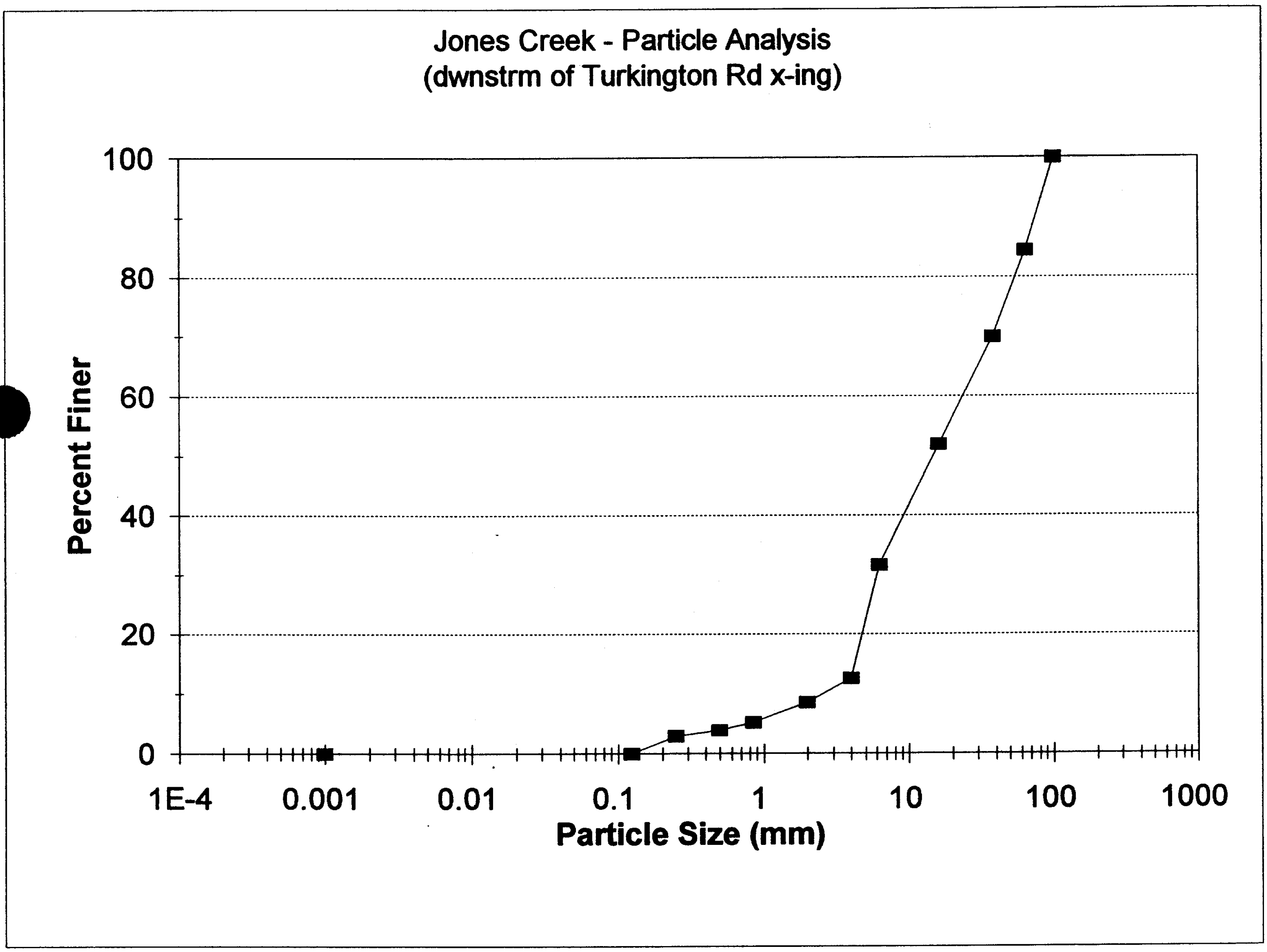
McCarty Creek - Particle Analysis
(800 m below bridge)
Percent Finer
100
80
60
40
32
20
19
0
1E-4
0.001
0.01
0.1
1
10
100
1000
Particle Size (mm)
Channel
Terrace

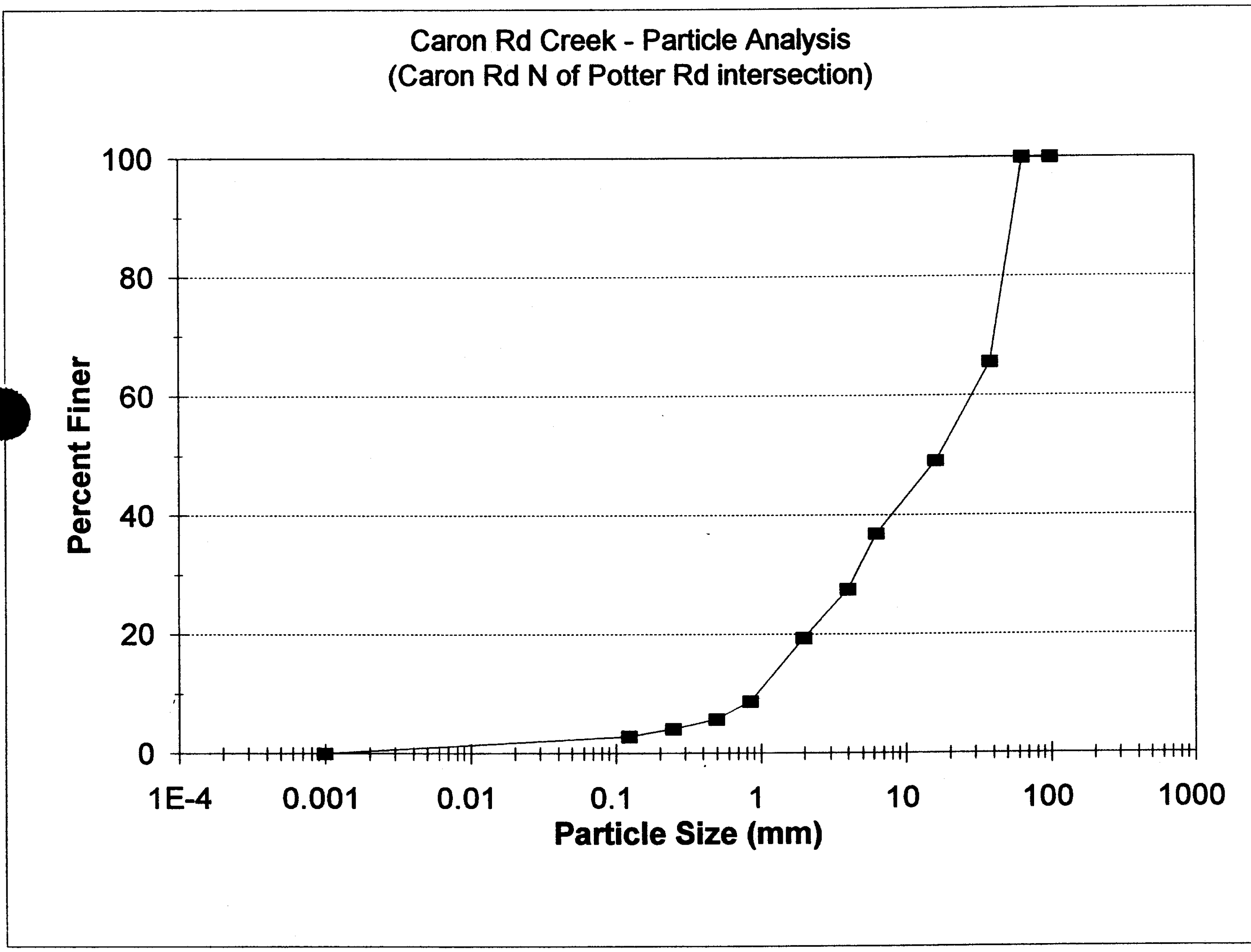


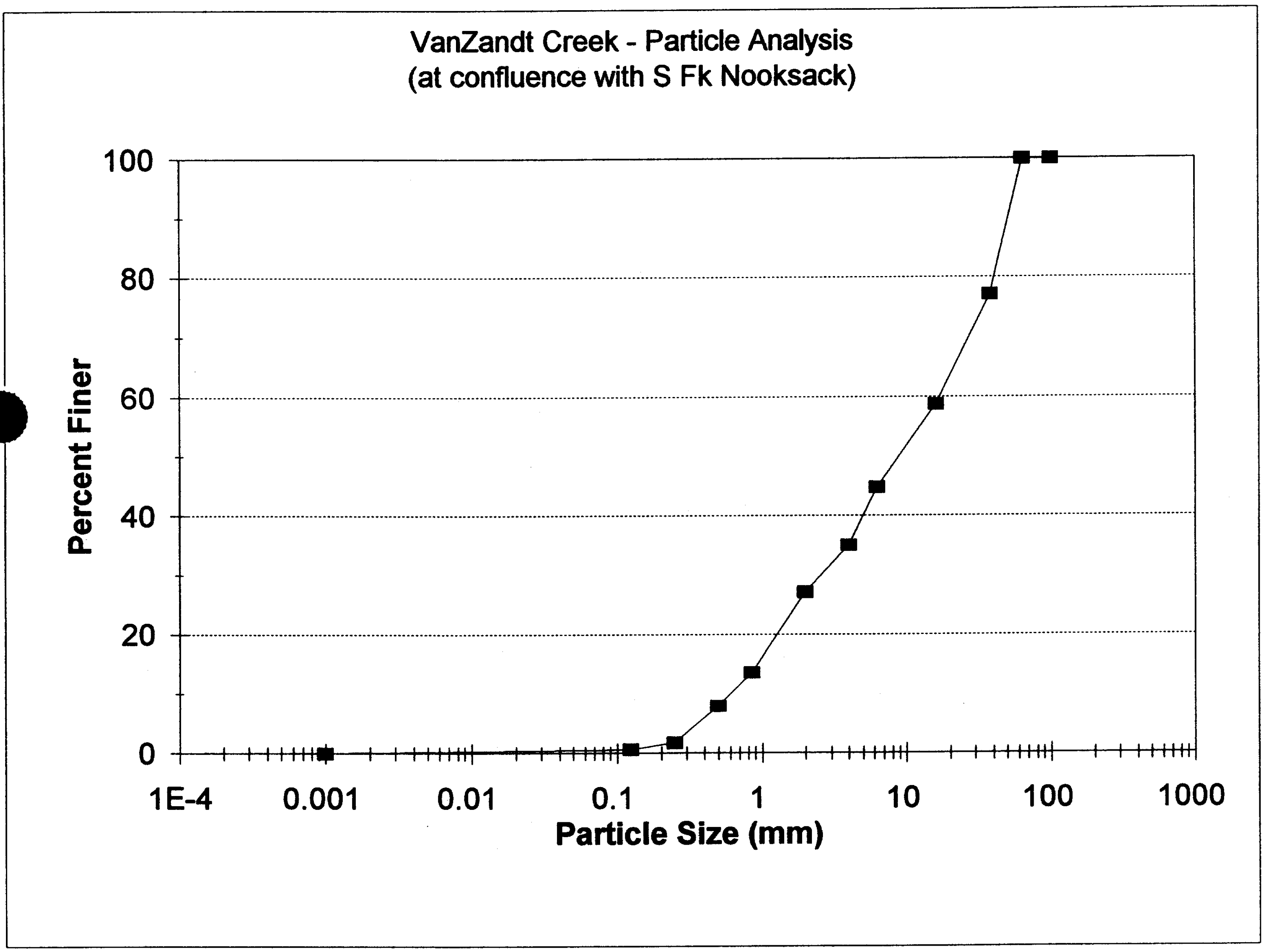
Jones Creek - Particle Analysis
(200m above bridge)
100
80
60
40
20
0
Percent Finer
1E-4
0.001
0.01
0.1
1
10
100
1000
Particle Size (mm)
Channel
Terrace

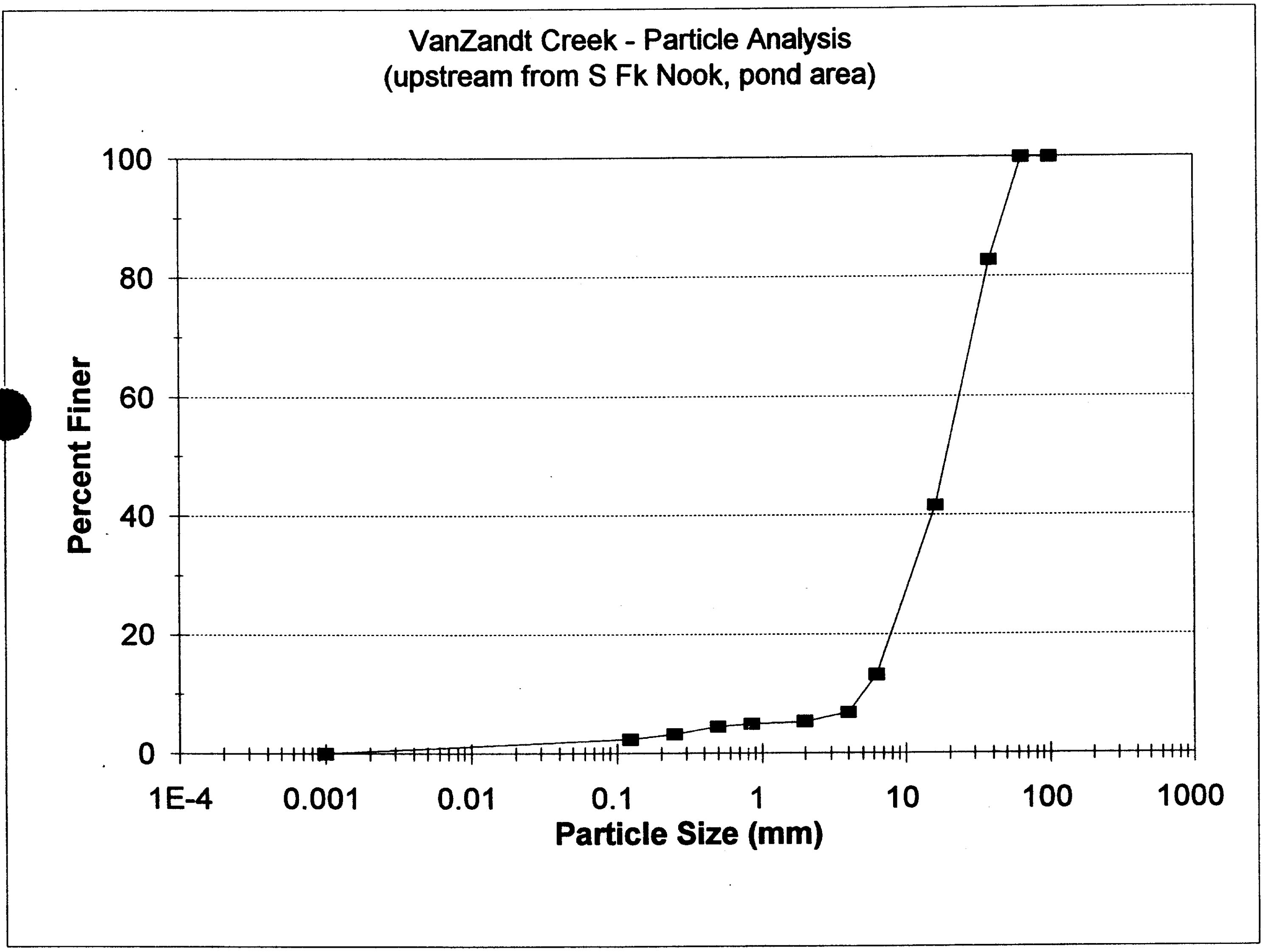

Jones Creek - Particle Analysis
(50m below upper bridge)
Percent Finer
100
80
60
40
20
0
1E-4
0.001
0.01
0.1
1
10
100
1000
Particle Size (mm)
Channel
Terrace

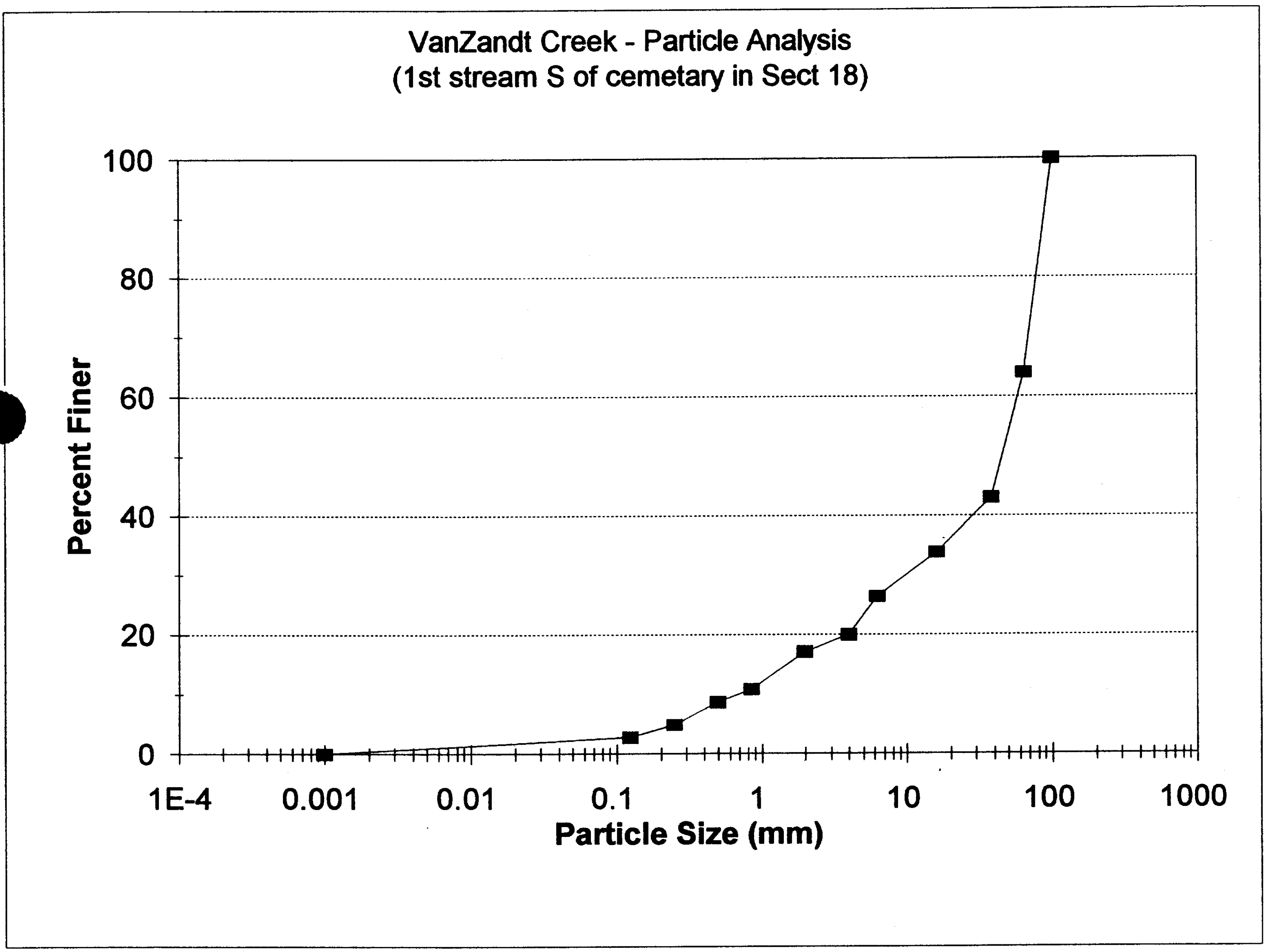

McCarty Creek - Particle Analysis
(downstream of Turkington Rd)
Percent Finer
100
80
60
40
20
0
1E-4
0.001
0.01
0.1
1
10
100
1000
Particle Size (mm)


Jones Creek - Particle Analysis
(dwnstrm of Turkington Rd x-ing)
Percent Finer
100
80
60
40
20
0
1E-4
0.001
0.01
0.1
1
10
100
1000
Particle Size (mm)

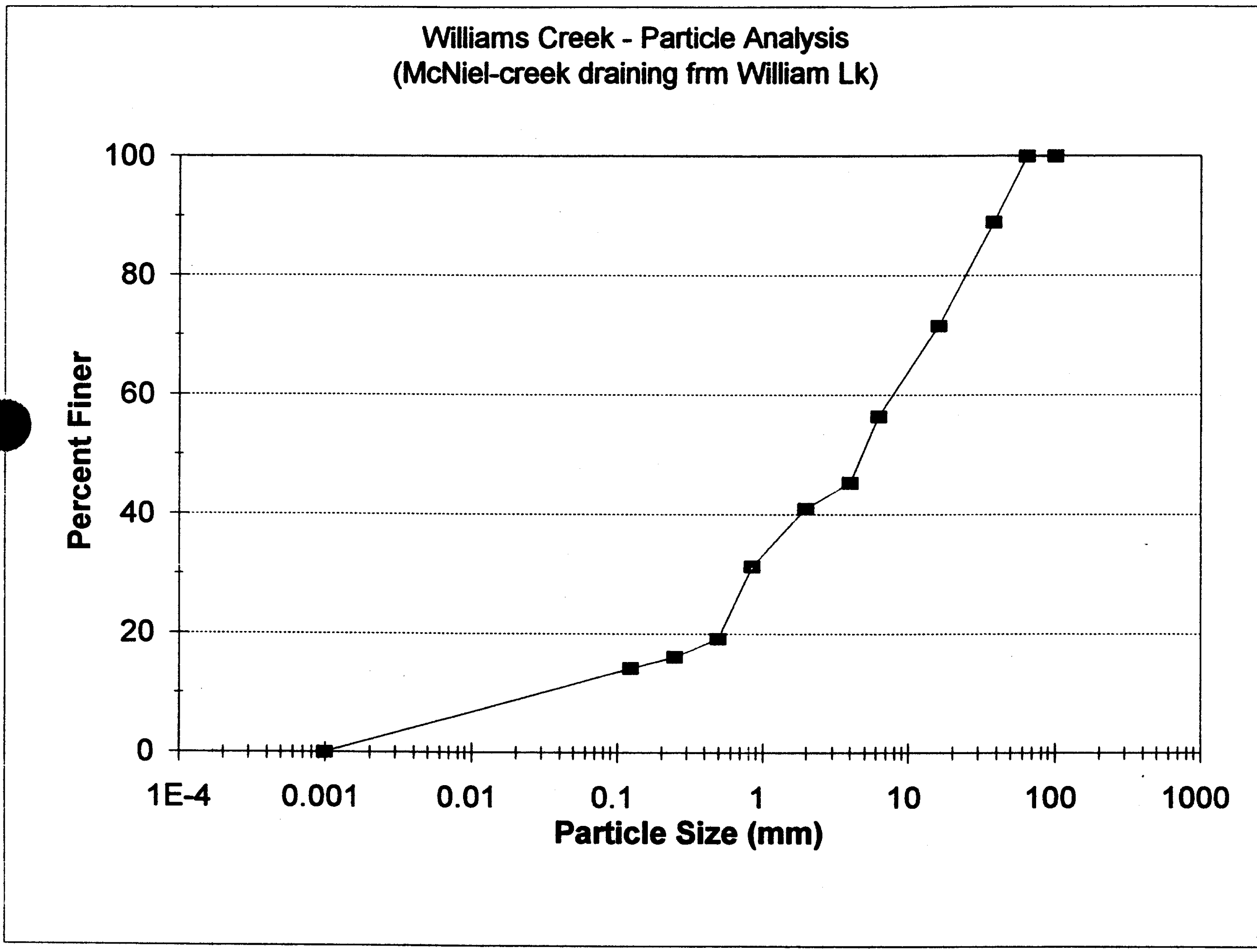

Caron Rd Creek - Particle Analysis
(Caron Rd N of Potter Rd intersection)
Percent Finer
100
80
60
40
20
0
1E-4
0.001
0.01
0.1
1
10
100
1000
Particle Size (mm)


VanZandt Creek - Particle Analysis
(at confluence with S Fk Nooksack)
Percent Finer
100
80
60
40
20
0
1E-4
0.001
0.01
0.1
1
10
100
1000
Particle Size (mm)

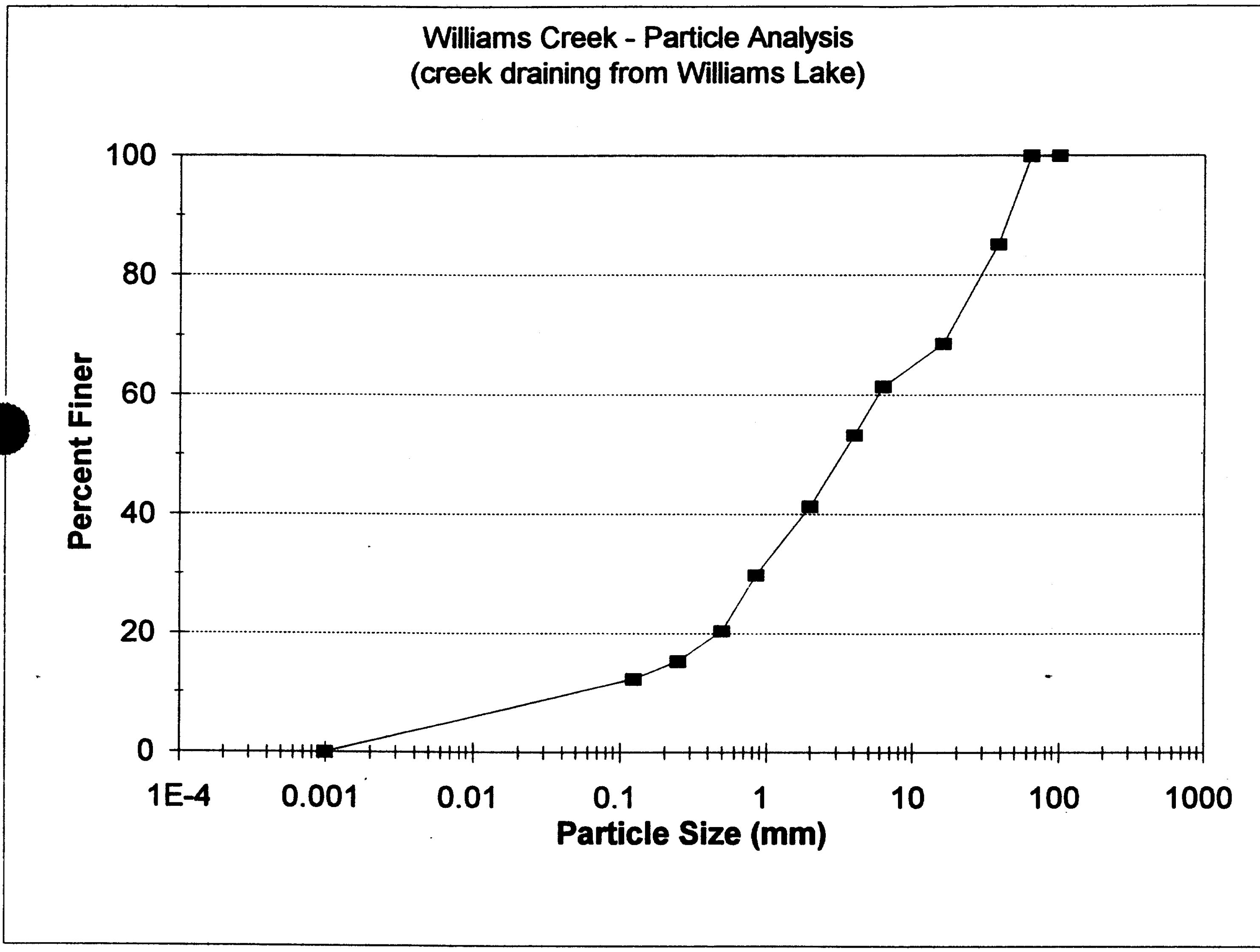

VanZandt Creek - Particle Analysis
(upstream from S Fk Nook, pond area)
Percent Finer
100
80
60
40
20
0
1E-4
0.001
0.01
0.1
1
10
100
1000
Particle Size (mm)

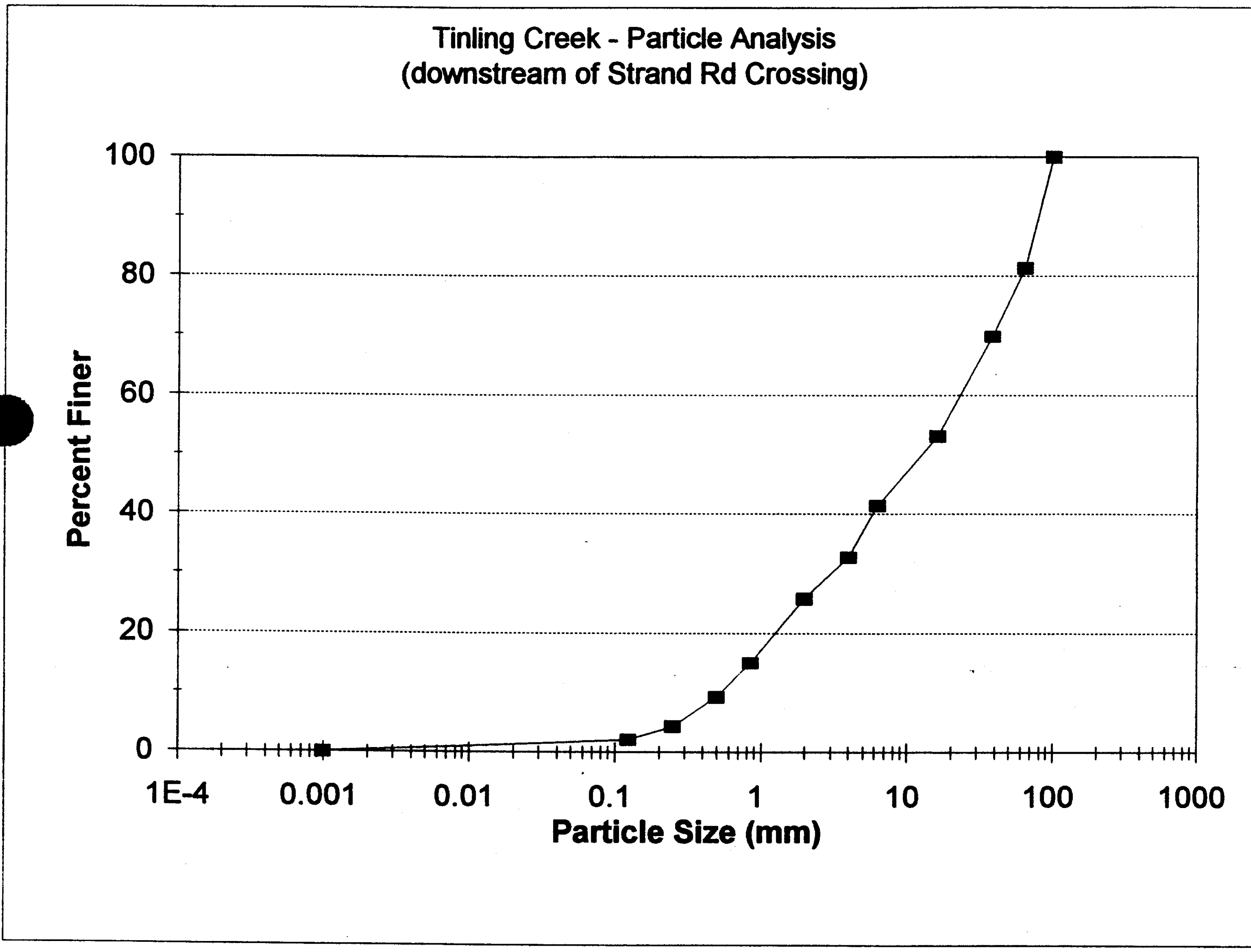


VanZandt Creek - Particle Analysis
(1st stream S of cemetary in Sect 18)
Percent Finer
100
80
60
40
20
0
1E-4
0.001
0.01
0.1
1
10
100
1000
Particle Size (mm)

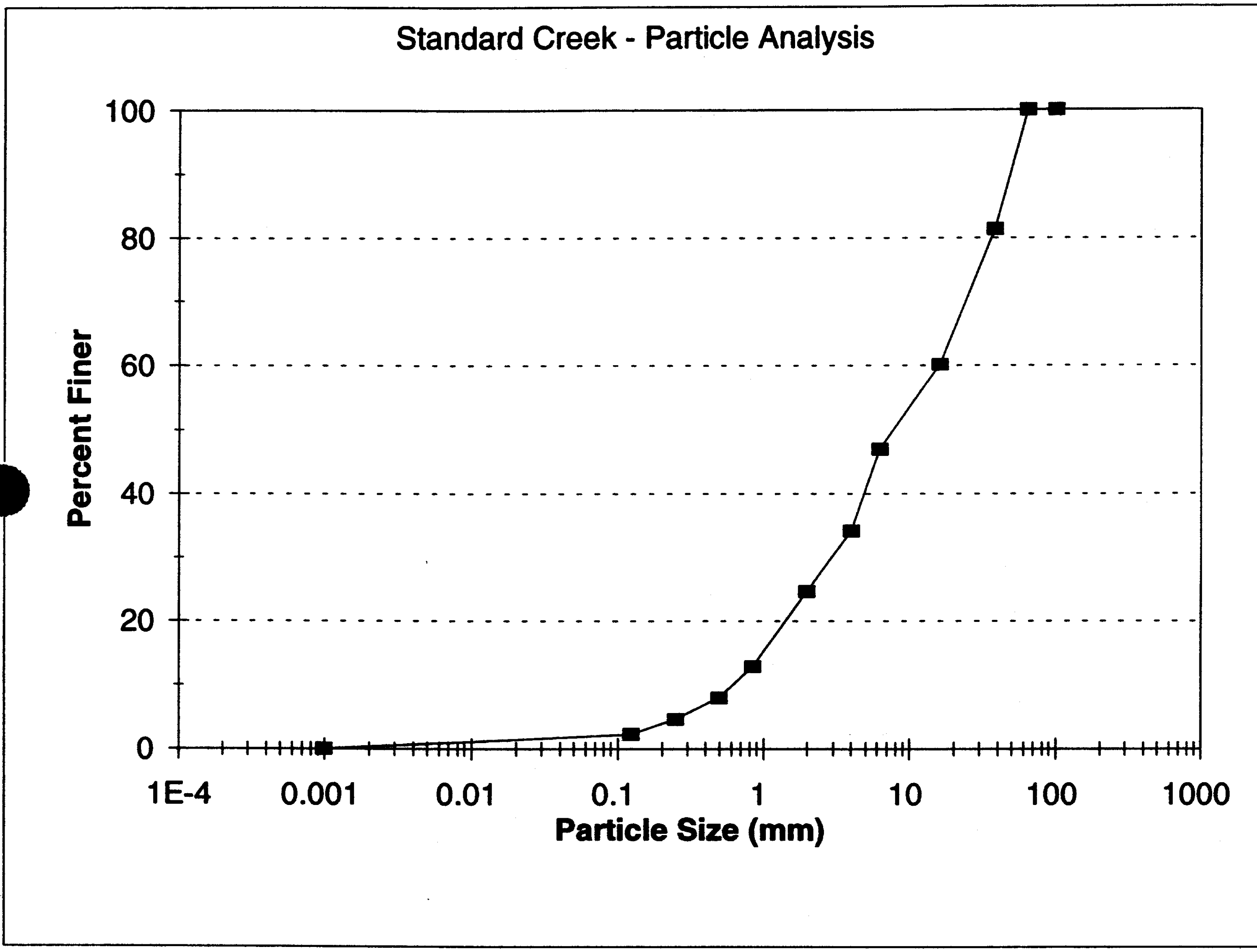


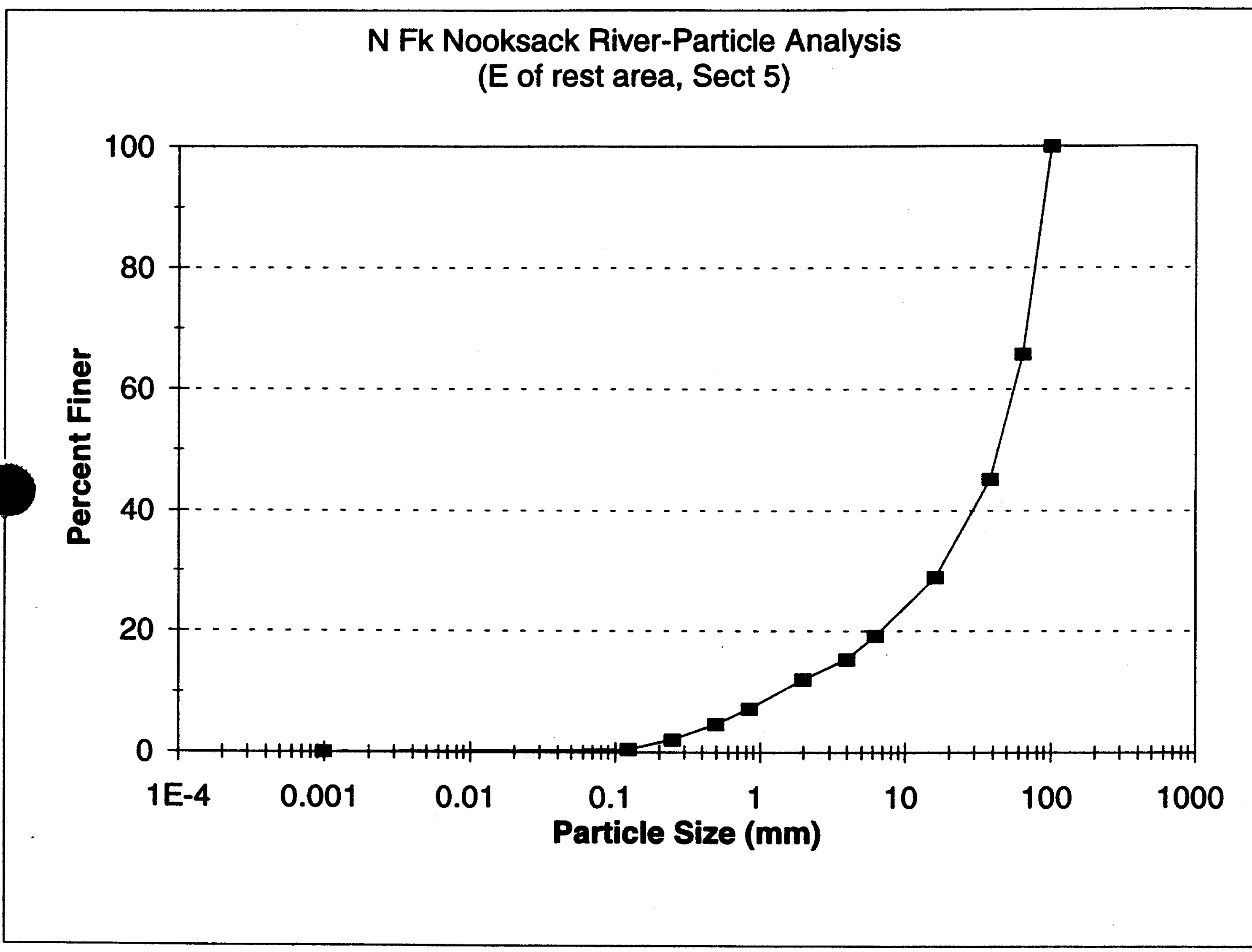
Williams Creek - Particle Analysis
(McNiel-creek draining frm William Lk)
Percent Finer
100
80
60
40
20
0
1E-4
0.001
0.01
0.1
1
10
100
1000
Particle Size (mm)

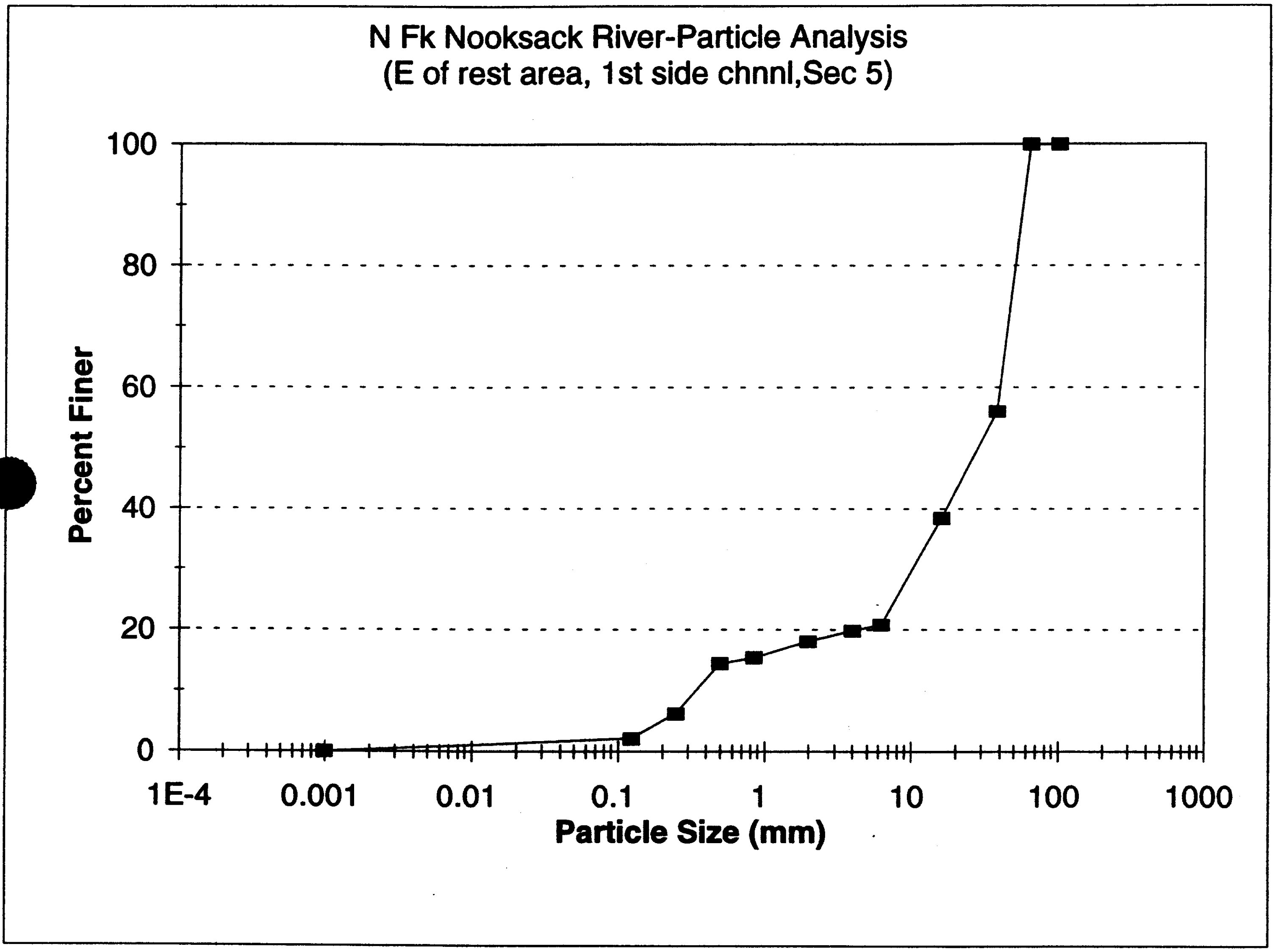

Williams Creek - Particle Analysis
(creek draining from Williams Lake)
Percent Finer
100
80
60
40
20
0
1E-4
0.001
0.01
0.1
1
10
100
1000
Particle Size (mm)

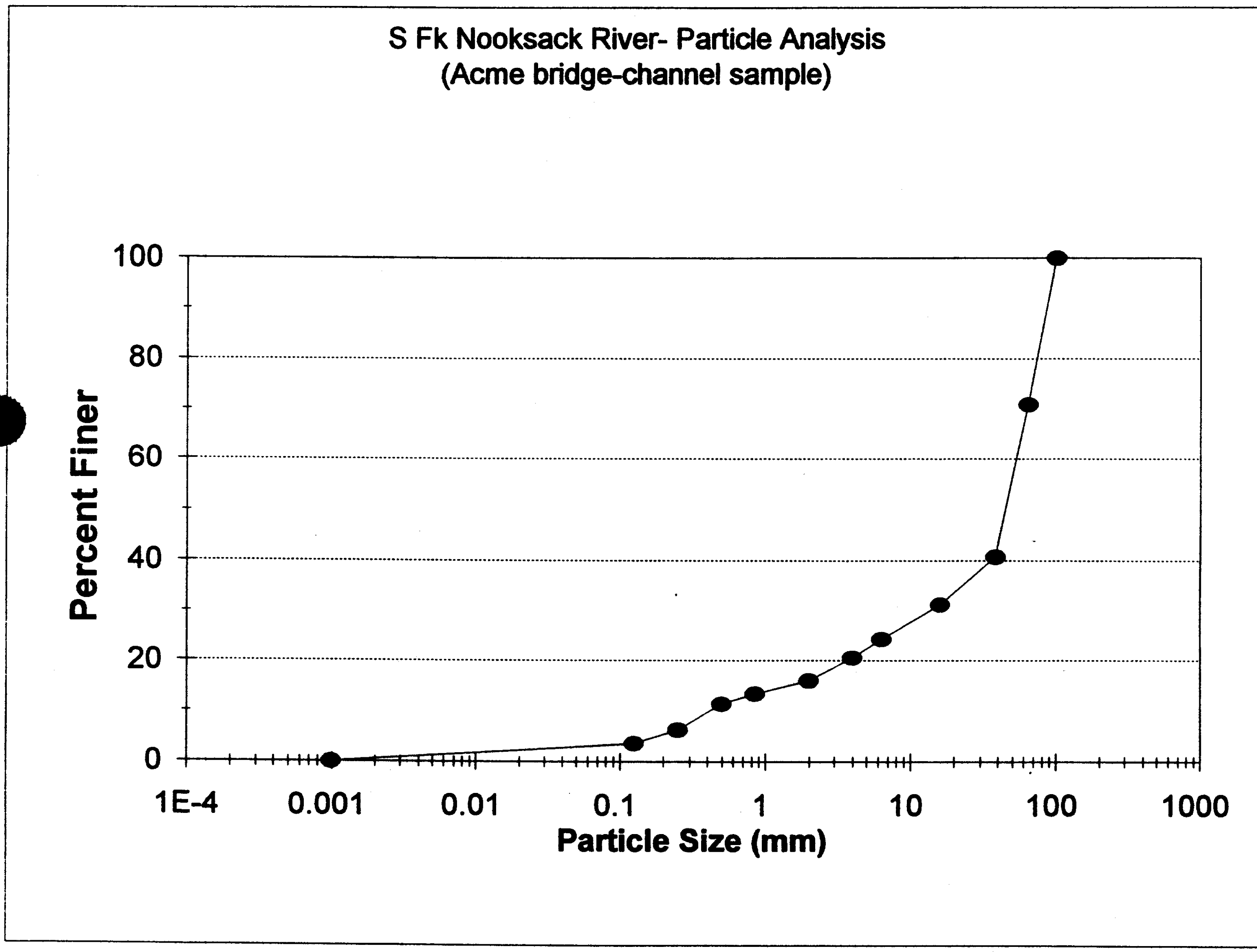


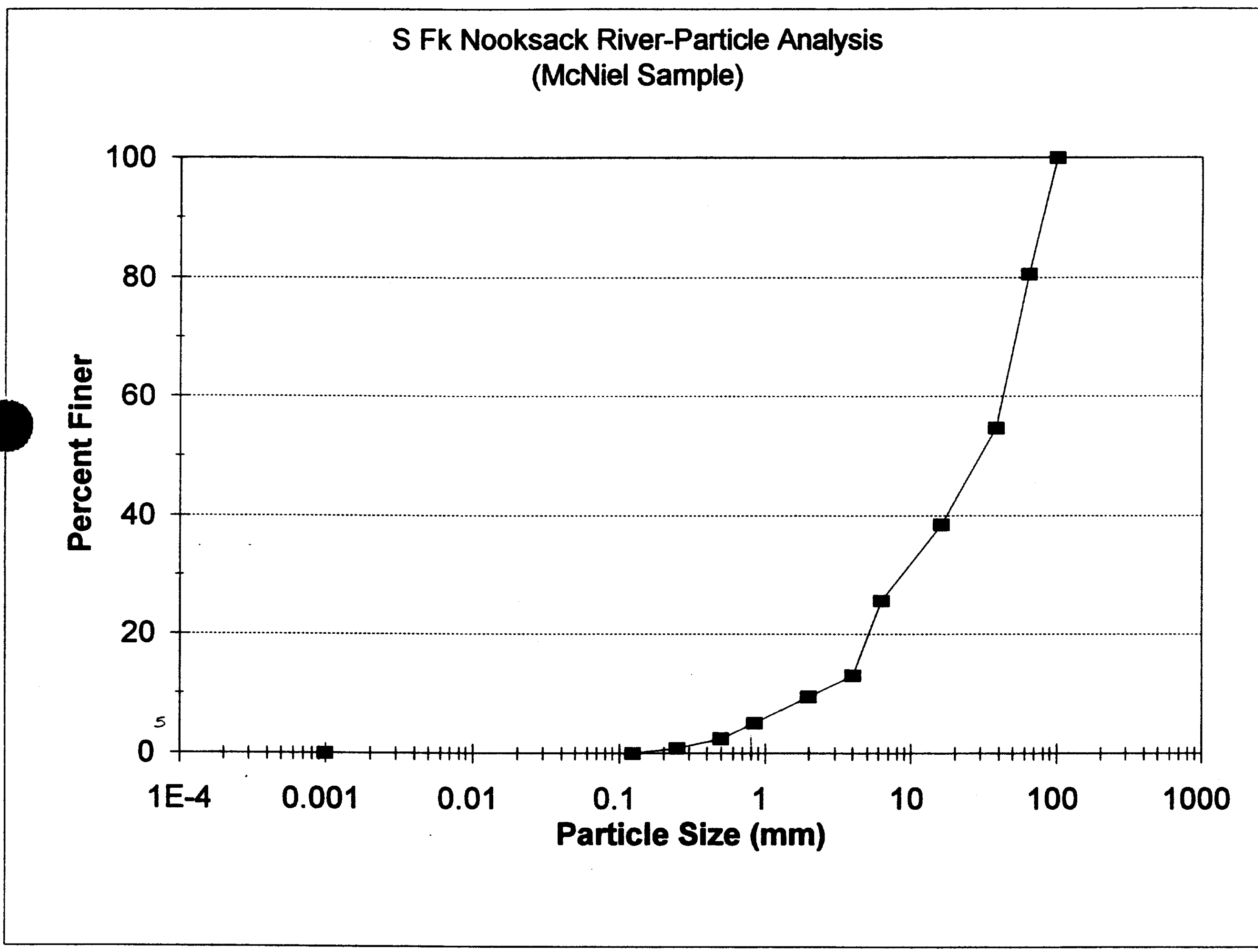
Tinling Creek - Particle Analysis
(downstream of Strand Rd Crossing)
100
80
60
40
20
0
Percent Finer
1E-4
0.001
0.01
0.1
1
10
100
1000
Particle Size (mm)

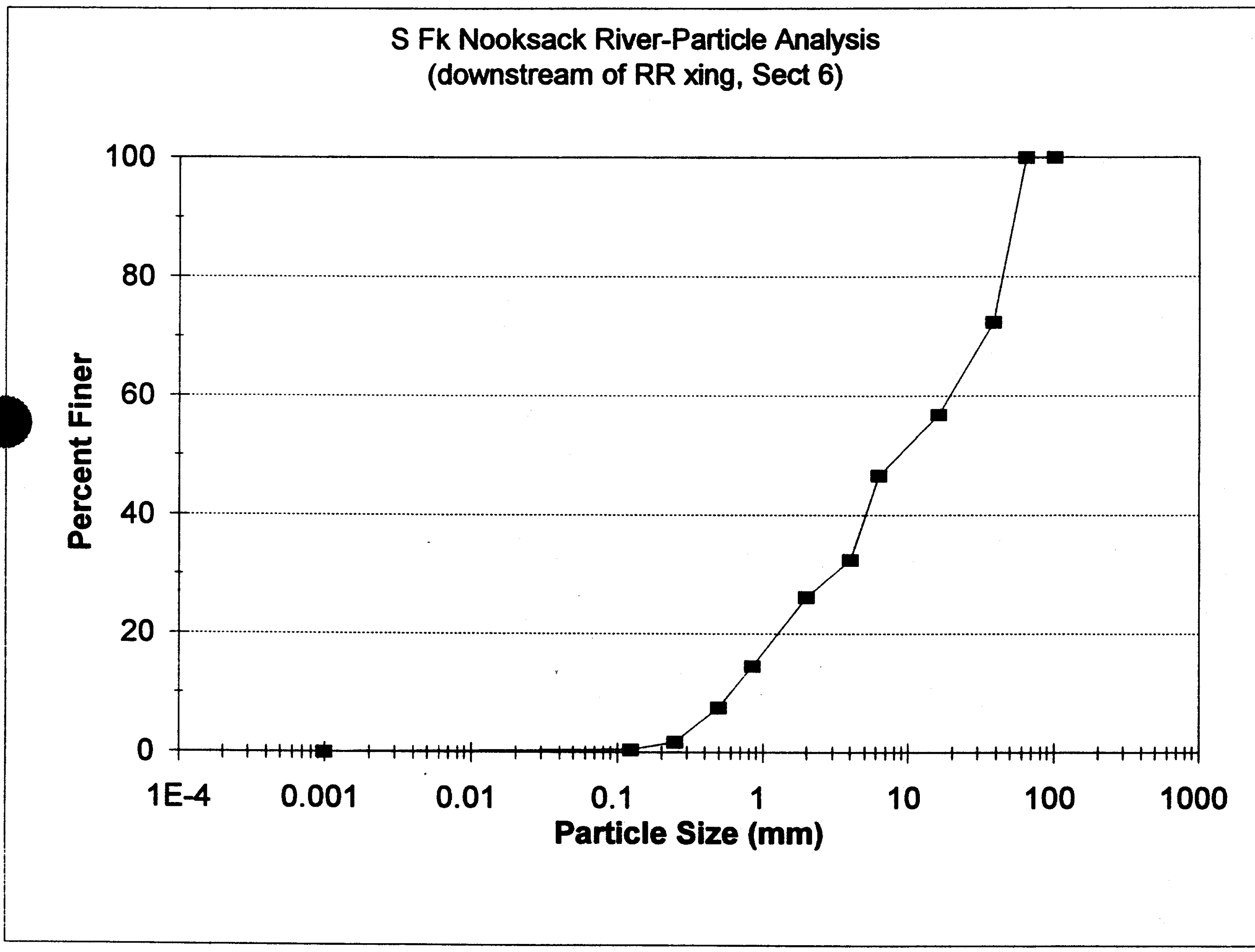

Standard Creek - Particle Analysis
100
80
60
40
20
0
Percent Finer
1E-4
0.001
0.01
0.1
1
10
100
1000
Particle Size (mm)

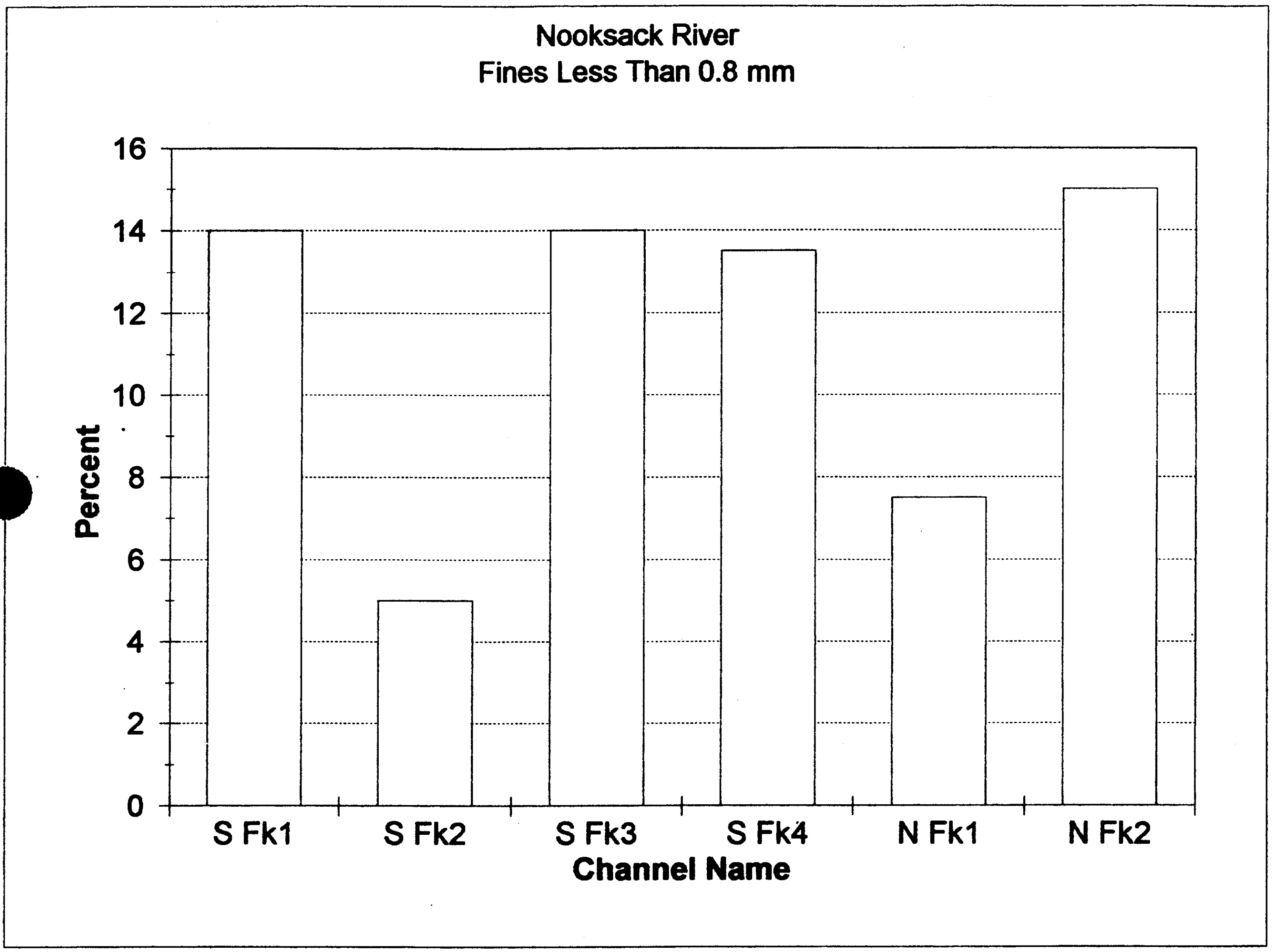

N Fk Nooksack River-Particle Analysis
(E of rest area, Sect 5)
Percent Finer
100
80
60
40
20
0
1E-4
0.001
0.01
0.1
1
10
100
1000
Particle Size (mm)


N Fk Nooksack River-Particle Analysis
(E of rest area, 1st side chnnl,Sec 5)
Percent Finer
100
80
60
40
20
0
1E-4
0.001
0.01
0.1
1
10
100
1000
Particle Size (mm)

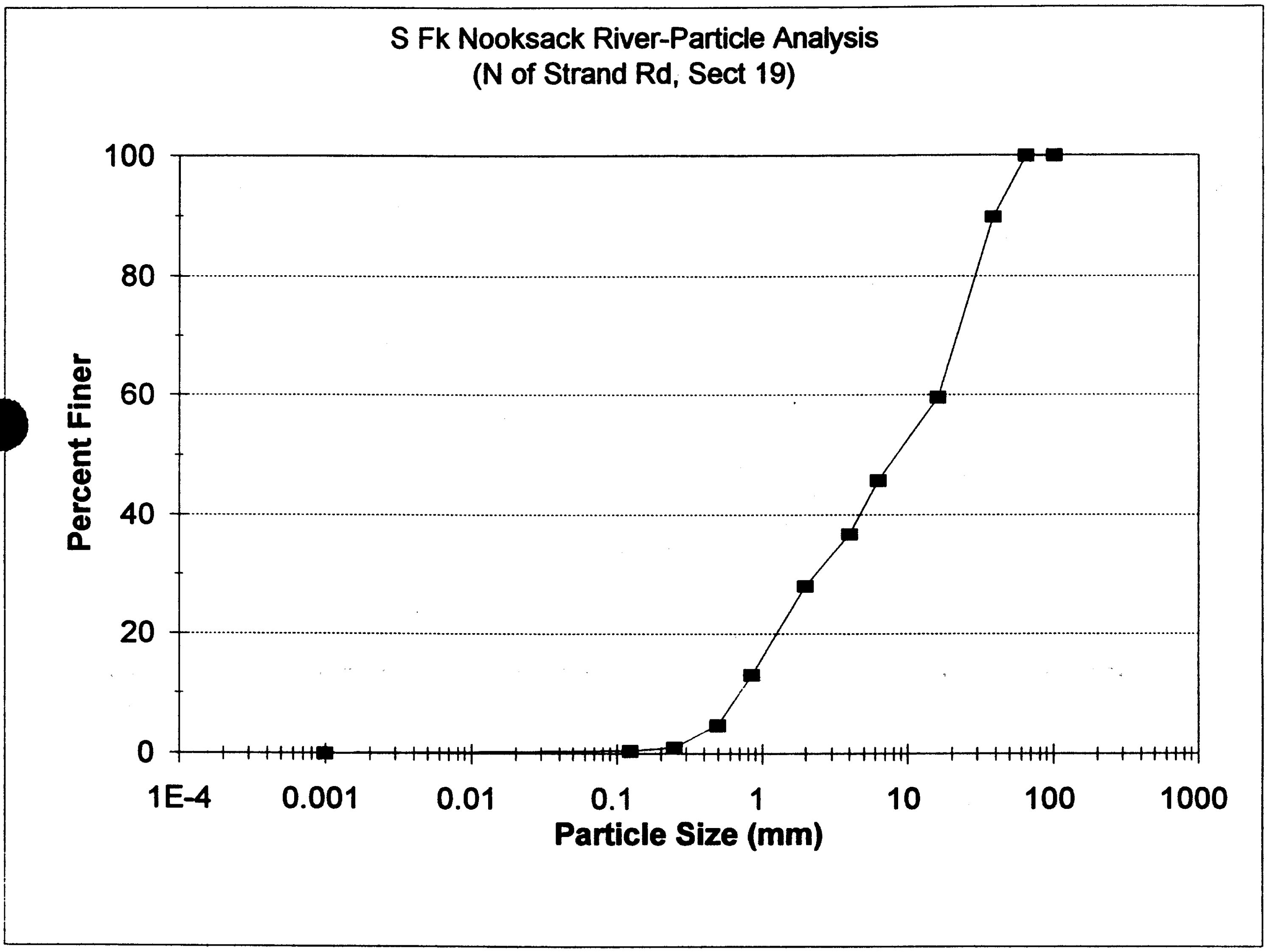

S Fk Nooksack River- Particle Analysis
(Acme bridge-channel sample)
100
80
60
40
20
0
Percent Finer
1E-4
0.001
0.01
0.1
1
10
100
1000
Particle Size (mm)

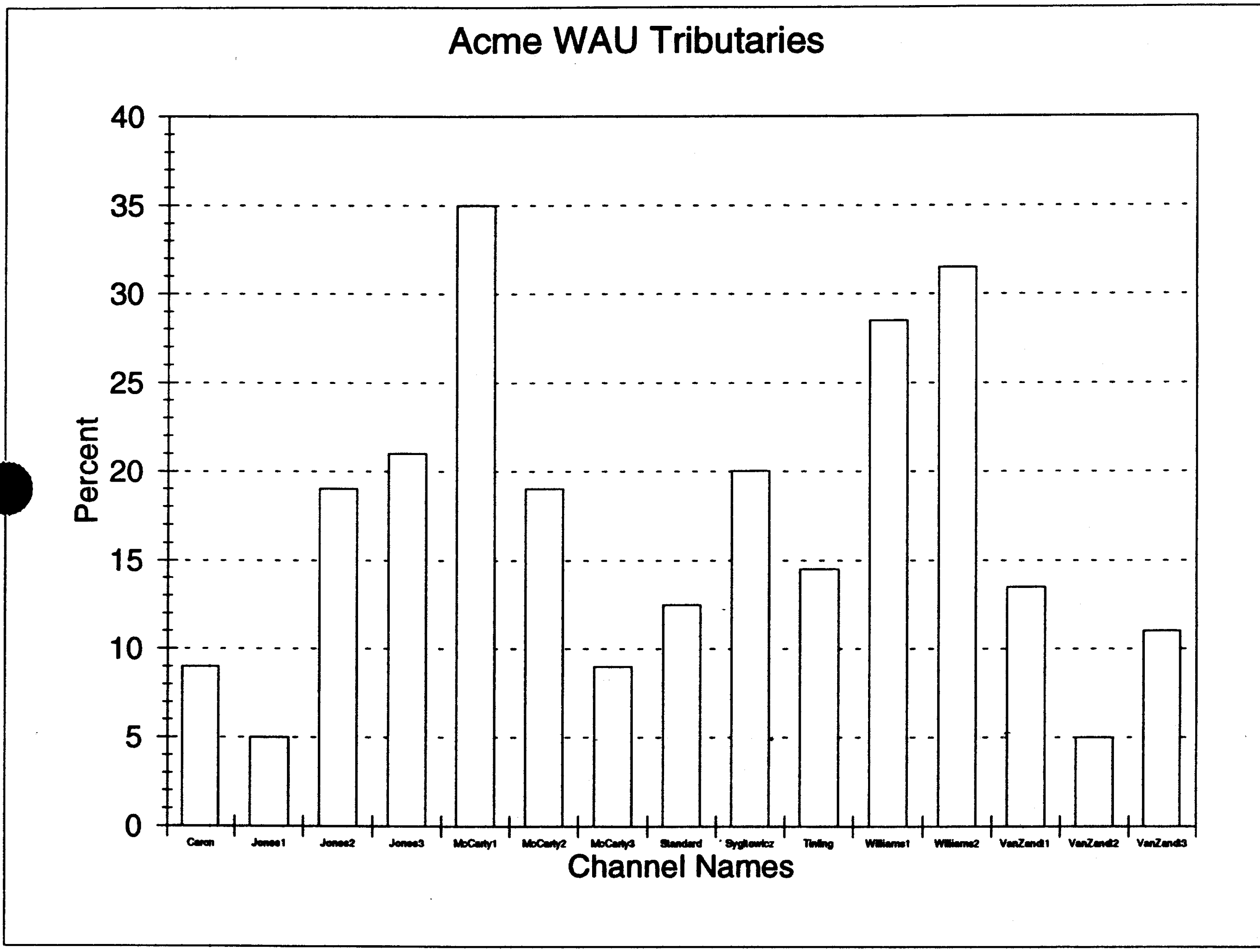

S Fk Nooksack River-Particle Analysis
(McNiel Sample)
100
80
60
40
20
5
0
Percent Finer
1E-4
0.001
0.01
0.1
1
10
100
1000
Particle Size (mm)


S Fk Nooksack River-Particle Analysis
(downstream of RR xing, Sect 6)
100
80
60
40
20
0
Percent Finer
1E-4
0.001
0.01
0.1
1
10
100
1000
Particle Size (mm)



Nooksack River
Fines Less Than 0.8 mm
Percent
16
14
12
10
8
6
4
2
0
S Fk1
S Fk2
S Fk3
S Fk4
N Fk1
N Fk2
Channel Name


S Fk Nooksack River-Particle Analysis
(N of Strand Rd, Sect 19)
100
80
60
40
20
0
Percent Finer
1E-4
0.001
0.01
0.1
1
10
100
1000
Particle Size (mm)



Acme WAU Tributaries
Percent
0
5
10
15
20
25
30
35
40
Caron
Jones1
Jones2
Jones3
McCarty1
McCarty2
McCarty3
Standard
Syglowicz
Tinling
Williams1
Williams2
VanZandt1
VanZandt2
VanZandt3
Channel Names

# APPENDIX 6-4
# FORM E-6

**Form e-6** Geomorphic Unit: 1 and 2 (South Fork Nooksack and its floodplain)

| Input Factor | Conditions | Response Potential | Relative Sensitivity |
|---|---|---|---|
| **Coarse Sediment** | Relatively low sediment supply | Can aggrade and braid | High |
| **Fine Sediment** | Relatively low – transport reach | Can increase with increasing coarse sediment aggradation | Moderate |
| **Peak Flow** | Unknown | Can scour | Moderate |
| **Large Woody Debris** | Low wood | Create ponds | High |
| **Catrastrophic Damage** | No | No | Low |

**Form e-6** Geomorphic Unit: 3 and 4 (Slough channels)

| Input Factor | Conditions | Response Potential | Relative Sensitivity |
|---|---|---|---|
| **Coarse Sediment** | Relatively low supply | Can aggrade the channel | High |
| **Fine Sediment** | Relatively high levels | Can increase | High |
| **Peak Flow** | Floodplain channels | Overbank flows | Low |
| **Large Woody Debris** | Few pieces | Create ponds | High |
| **Catrastrophic Damage** | N/a | N/a | N/a |

Form e-6 Geomorphic Unit: 5 (Alluvial and debris flow fans)

| Input Factor | Conditions | Response Potential | Relative Sensitivity |
|---|---|---|---|
| **Coarse Sediment** | Low to high supply depending on fan | Can aggrade | High |
| **Fine Sediment** | Low to high supply depending on fan | Can be high when coarse sediment is high | High |
| **Peak Flow** | Variable | Depends on sediment supply | High during high sediment supply; low during low sediment supply |
| **Large Woody Debris** | Typically low wood | Create pools – store sediment | High |
| **Catrastrophic Damage** | | Can get hit by debris flow and torrent | High |

Form e-6 Geomorphic Unit: 6 (Tributaries with upland drainages located above Unit #5)

| Input Factor | Conditions | Response Potential | Relative Sensitivity |
|---|---|---|---|
| **Coarse Sediment** | Generally low supply | Can aggrade | |
| **Fine Sediment** | Variable | Increase with increases in coarse sediment or from erosion upstream | High |
| **Peak Flow** | - | Erode banks; scour perhaps | High |
| **Large Woody Debris** | Few pieces of wood | Create pools; store sediment | High |
| **Catrastrophic Damage** | N/a | N/a | N/a |

**Form e-6** Geomorphic Unit: 7 (Mountain tributaries)

| Input Factor | Conditions | Response Potential | Relative Sensitivity |
|---|---|---|---|
| **Coarse Sediment** | High to low – depends on channel | Can aggrade particulaly behind jams | |
| **Fine Sediment** | - | Fine sediment quickly moved through | Low |
| **Peak Flow** | Very coarse substrate | Difficult to mve large substrate (boulder) | Low-Moderate |
| **Large Woody Debris** | Variable – often low since torrents | Temporary sediment storage | Moderate |
| **Catrastrophic Damage** | - | Debris flows and dam-break floods | High |

# APPENDIX 6-5

# LEE BENDA AND ASSOCIATES, INC.

SCIENCE FOR MANAGING DYNAMIC ENVIRONMENTS
hillslope geomorphology
fluvial processes

Mark Hitchcock
25469 Old Day Creek Road
Sedro-Woolley, WA 98284

January 24, 1999

Dear Mr. Hitchcock,

It has come to my attention that an error exists in the channel assessment of the Acme Watershed Analysis. The alluvial/debris fan channel segments have gradients of 4 to 8% and the next upstream segment, referred to as mountain tributary channels, have gradients of 10%. The error is the omission of a 9% channel gradient within the channel segment classification. To rectify this problem, I recommend that mountain tributary channels be reclassified as having a slope range of between 4 and 9%. This change should not cause any other additional changes or problems in the channel module and should not affect the management prescriptions.

Sincerely,

Lee Benda

Lee Benda Ph.D.
Geomorphologist

1314 NE 43rd Street Suite 205, Seattle, WA 98105-5832 (206) 633-1790 fax (206) 633-1792